



SAFETY AND HEALTH FOR ENGINEERS

Third Edition

ROGER L. BRAUER





WILEY

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FOR ENGINEERS

THIRD EDITION

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Tolono, Illinois

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PREFACE TO THE REVISED EDITION

Since the publication of the first and second editions of this book, some things *have not* changed. Today, engineers still have a moral, legal, and ethical responsibility to protect the public in professional practice and in design of products, buildings, processes, equipment, work, and workplaces. The importance of safety in engineering education remains a concern for most engineering degree programs. There is still a need for safety and health specialists who help employers, manufacturers and others to protect people, property and the environment. They must recognize, evaluate, and control hazards. They must assist management, supervisors, and workers to use safe practices so all employees return home safely each day. Yes, there is still a need for this book.

Also since the second edition, many things *have* changed. There are regulatory changes, changes in technology, changes in business practices, and broadening of participants in achieving safety. Perhaps the greatest changes have resulted from the Internet and its influence on information, communications, and work. While the third edition of this book reflects many such changes, it is impossible to capture all changes affecting safety. In addition, change is constant and a book cannot keep up with change. That is why this edition tries to link readers to new information resources.

Technology continues to change. Computer technology has changed the toolbox for nearly every professional field and it impacts safety practice as well. At first, personal, desktop computers took over the role of most mainframe systems. Now applications work on cell phones and tablets and allow individuals to carry tools with them in their pockets or briefcases. Technology has compressed information storage. Volumes of paper records, photographs, hard copy books, and other documents now fit into memory devices the size of a button.

Not only has the Internet offered an explosion in information and access to it, it has linked people through new devices in new ways. For nearly a century, the telephone linked places. You called a business or home. Today, cell phones and other devices link individuals wherever they are. The links offer voice, text, photos, applications, and data in ways never possible. Concurrently, a challenge for everyone is differentiating quality information from misinformation in nearly every field, including safety and health. Individuals must decide what is valid and reliable information.

Technology has changed businesses and the global economy as well. Companies no longer need layers of employees who formerly collected, processed, evaluated, and reported on business information vital to success. Anyone authorized at any organizational level can access data and reports electronically.

Today, companies organize work differently from the past. The hierarchical structure of work and its supervision has shifted to increased use of teams. The role of supervisors has shifted to team leaders with leading, coaching, and mentoring responsibilities. Work teams have increased participation in recognizing and controlling hazards related to their work, rather than reporting problems to a safety department for action.

The overall field of safety has changed. Safety and health professional work demands higher levels of education. Roles of safety and health professionals have shifted from implementing safety details to overseeing strategies, methods, and practices that achieve safety. The changing roles reflect the business practice of moving safety knowledge and skills deeper into organizations and workgroups.

There continues to be a convergence of related areas. In the 1960s and 1970s, the United States passed a range of laws to protect workers and the environment. At that time the approach was one of specialization in safety, industrial hygiene, environment science and engineering, fire protection, occupational health and nursing, and related fields. More recently, many companies have combined these functions into a single organizational unit. That increased the need for generalists while retaining a need for specialists. Since the tragedy at the World Trade Center on 9/11/2001, some in safety and health have security as an additional responsibility.

Another kind of change involves laws, regulations, and standards. The regulatory system in the United States continues to assign responsibility to government units. There continues to be a shift from state and local government toward the federal level to decide how best to protect people, property, and the environment. The system relies heavily on government prescribing details in regulations and standards.

In the United Kingdom and other Commonwealth countries, there was a shift away from central government toward risk management assigned to employers, manufacturers, and workers. In the United States, some have begun to adopt this approach.

In addition, there is a growing emphasis on management systems and a global expansion of standards for them. The shift started with general business management systems, such as those covered by ISO 9000. Now they also encompass environmental, safety, and health management systems.

An original goal for this book was helping engineers and others gain a broad, quick overview of safety and health practices. Another goal was identifying some of the detailed resources that may provide expanded help in specific topics. An additional goal was making the content easy to read and comprehend.

It has been rewarding to learn how the book continues to meet these goals. One exciting kind of feedback has been meeting people who have used this book. A number reported that the book helped them improve their understanding of safety and health. Others reported that the book remains a key reference at their desks. An exciting report was from a group of Indonesian engineers completing a special program in safety engineering at a university in the United States. They voted this book the easiest to read during that program.

Completing this third edition remains a work devoted to the love of the engineering and safety professions, even after retirement from full-time employment. While completing my education, my goal was to find ways to apply engineering for the benefit of people. With this third edition, my hope is to continue helping engineers who have an ethical and professional responsibility to protect the health, safety, and welfare of the public. I also hope the book helps those seeking roles in safety and health or expanding such roles.

I must continue to thank those who guided me into the safety, health, and ergonomics fields from my engineering background. Many helped motivate me to complete the first, second, and now the third editions. My greatest thanks goes to my wife, Char, who has supported my professional work over the years. I also thank my children, Michelle and David, and my grandchildren, Matt, Michaela, Nicolas, and Reagan, who also gave me support and motivation while tolerating time often stolen from or interrupting family activities.

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PART I

INTRODUCTION

THIS PORTION of the book identifies the reasons for protecting the public. It provides some historical background leading to an emphasis on safety and health in work and products. It outlines several fundamental concepts for safety that help readers to think about and deal with safety and safety issues.

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CHAPTER 1

THE IMPORTANCE OF SAFETY AND HEALTH

1-1 INTRODUCTION

Modern Western society continues to place a high value on human life. That was not always the case. Even today, some societies place a limited value on human life.

In the United States today, life expectancy for males is 76 years and 81 years for females and increasing slowly. Some other developed countries have slightly higher life expectancies. Some underdeveloped countries have life expectancies around 50 years.

In the past few centuries, engineering and medicine have all but eliminated some diseases that previously were major threats. Examples are smallpox, typhoid, cholera, bubonic plague, diphtheria, tuberculosis, and polio. Medicine has contributed vaccinations, improved treatments, and the use of antibiotics. Engineering contributed sanitation systems to manage human and other waste and to prevent the spread of diseases and illnesses by treating water.

Today we are on the threshold of biological medicine that helps with diagnosis and treatment of disease. A few drops of blood can test for nearly 1,000 medical conditions. Mapping of the DNA molecule and DNA testing can now link many diseases to individual conditions. Biologically grown substances, tissue, and even organs are leading to revolutionary treatments.

The industrial revolution occurred between 1760 and 1840. Early in the industrial revolution, the life expectancy for the working class in Manchester, England, was 17 years. For the gentry living in the country on manors, life expectancy was 35 years. Child labor was common. The industrial revolution introduced new hazards to workers. Early on, the rate of injury and death at work was very high, often from machines. While the rates have come down a lot, there is still much to be done. New equipment and technology have added hazards, often extending from workers to the general population. For example, the automobile continues to cause significant injury and death to the general population. The number of chemicals and materials in daily use has exploded. The *CAS Registry*[1] contains more than 65 million entries with 15,000 additions daily. There are about 300,000 inventoried or regulated substances. We know little about the safety and health hazards of many of these substances.

The industrial revolution spawned a major safety movement. The result was government laws and regulations aimed at protecting workers. Early in 1900, many new organizations devoted to safety and health were founded. One surviving example is the National Safety Council. There were many others at national, state, regional, and industry levels. Many no longer exist. Another derivative of the industrial revolution is workers' compensation, the idea that workers receive compensation for work-related injuries.

What is the value of a human life today? In defending proposed regulations, federal agencies often estimate the value of human life. The Environmental Protection Agency has used $9.1 million. The Food and Drug Administration estimated human life at $7.9 million. The Transportation Department set human worth at $6 million. The average payout for victims of the 9/11 terrorist tragedy in New York in 2001 was $2.1 million. Some insurance companies use $50,000 per year in managing insurance decisions.

Governments, employers, and individuals spend significant money to avoid loss of human life and to prevent injuries and illnesses. Many buy insurance to cover the financial risks related to death, injury, illness, and property loss. For employers, there is also the resulting return on such investments.

Many professions, including engineers and others, play significant roles in these protective endeavors. Protection focuses on people, property and the environment. While all are important, this book will focus primarily on people. The book will concentrate on matters that cause injury, illness, and death. Injury, illness, and death can occur at work, at home, while traveling and during leisure and recreational activities. This book mainly addresses work situations. However, discussion of some topics extends to other activities as well.

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1-2 WHY SAFETY?

Why is safety important? Why bother with it? There are three general reasons.

One reason is *humanitarianism*. Many societies place value on human life and welfare. Not all societies have the same degree of regard for people. Having value for human life is a moral basis for the field of safety and health.

Another reason is the *law*. Different societies use different standards for right and wrong. Societies set standards of conduct through laws and regulations. This reason for safety derives from the first. Laws define a society's moral code. The laws protect the safety, health, and welfare of individuals, property, and the environment.

Cost is a third reason. Some governments and businesses have established a value for human life. Some have established values for injuries and illnesses. The costs involved in injury, illness and death are part of the economic system of a society. So are costs for loss of property. Damage to the environment may also incur costs as part of business. Society often defines the costs through laws.

Humanitarianism

The Value of Human Life and Property Humanitarianism has many aspects derived from the value placed on human life, property and the environment in which we live. Humanitarianism represents the moral part of safety and health. Protecting people is the right thing to do, the moral action.

Humanitarianism varies with societies. Some place a high value on human life, property, and the environment. Others have little regard for these elements, especially when one group has different views from other groups. The differences may involve political or religious factors or other characteristics.

Professional Conduct and Ethics The moral aspect of safety and health often is linked to professional ethics. Many codes of professional conduct and ethics place high value on human life. For example, the National Society of Professional Engineers (NSPE) places protection of people at the top of its Code of Professional Conduct:[2]

I. Fundamental Canons
Engineers, in the fulfillment of their professional duties, shall:
1. Hold paramount the safety, health, and welfare of the public.

The Code continues later with the first Rule of Practice:

II. Rules of Practice
1. Engineers shall hold paramount the safety, health, and welfare of the public.
2. If engineers' judgment is overruled under circumstances that endanger life or property, they shall notify their employer or client and such other authority as may be appropriate.

There are other codes of ethics and professional conduct for those involved in safety and health. The codes have similar provisions placing high importance on protecting people, property, and the environment.

Corporate Social Responsibility (CSR) Many companies have set a moral standard for their businesses that defines responsibilities to their stakeholders. These companies make a commitment to those they serve, including employees, customers, communities and others. Corporate Social Responsibility refers to operating a business in a manner that accounts for the social and environmental impact created by the business. Often CSR policies include commitments to the safety and health of workers, customers and communities, and action plans to implement them. The Internet shows many sources of help with CSR and examples of corporate CSR statements and action programs.

In 1984, chemical releases in Bhopal, India, killed between 2,300 and 16,000 people (depending on estimates) and harmed as many as 550,000 others. As a result, the American Chemical Society set up a program called "Responsible Care." This program reflects the moral basis for the field of safety and health. The program sets standards that guide producers and users of chemicals in protecting people, property, and the environment.

Sustainability Another moral concept involving protection of people, property, and the environment is sustainability. Sustainability is similar to CSR. One definition of sustainability is "improving the quality of human life while living within the carrying capacity of supporting eco-systems." Sustainability involves three elements: economy, society, and environment.

One study asked senior executives from around the world to rank their top ten challenges. Overall, sustainability came in ninth. The European Union (EU) has proposed setting sustainability reporting requirements as part of the Global Reporting Initiative (GRI). The goal is to improve transparency and accountability to the public.

Some studies have included safety and health as part of the sustainability concept. Safety and health are simply parts of the societal element of sustainability. The Center for Safety and Health Sustainability[3] addresses ways to assure that employee safety and health become part of sustainability globally.

Laws, Regulations, and Standards

The domain of laws, regulations and standards that require protection of people, property and the environment has many

parts. Individuals, companies, and organizations seek to comply with them. Part II of this book deals with laws, regulations, and standards in greater detail.

Government Laws, Regulations, and Standards In general, society codifies protection through laws enacted at international, national, state or province, and local government levels. Often, government agencies issue regulations and standards as interpretations of laws. Laws may conflict with each other, a problem for those trying to comply.

Voluntary or Consensus Standards In addition, groups of interested parties, such as companies, industry groups and associations or others, may create and publish voluntary or consensus standards applicable to their groups. A variety of associations and organizations engage in the creation of these standards.

Standards of Practice Finally, standards may refer to standards of practice. These are generally accepted practices by crafts, professions, managers or others without formally codifying them.

Costs

There are many kinds of costs associated with the protection of people, property, and the environment. One way to discuss costs involves dividing costs into direct and indirect costs.

Direct Costs For safety and health, there are direct costs focused on prevention of injury, illness, and death. Examples are training on how to perform jobs properly and safely. There are costs for equipment and clothing to prevent injuries, illness, and deaths. There are costs to complete work effectively.

There are safety costs for employers. Examples are creating a brand that includes safety concepts and creating loyalty of employees and customers in support of safety. Costs may include creating a positive image for a company or a product that includes safety. There are costs to incorporate safety into designs and the testing of products and processes.

There are costs to comply with laws, regulations, and standards. There are costs to establish and operate safety management systems, covered in Part V. Preventive costs should have significant returns on investments and contribute to business financial success.

Indirect Costs When there is a loss, there are many possible costs. Treating injuries and illnesses incur costs. Deaths create costs. The costs may involve cleanup, recovery, repair, and replacement of materials, equipment and facilities and hiring and training new personnel. Investigations have expenses. Lost production and productivity cost money. Insurance and processing of insurance claims incur costs. There may also be costs related to preventing or resolving legal challenges related to loss events.

1-3 THE RECORDS

Many statistics tell stories about the protection of people, property, and the environment. Over the years, many people have helped improve the performance statistics. However, much remains to be done. In addition, change brings new challenges to address.

The terminology has changed over the years. Some time ago records tracked injuries, illnesses and deaths from "accidents." Today, records use the term "unintentional" instead, such as unintentional injury deaths.

Worldwide Record

The International Labour Organizations (ILO) estimates[4] that around the world:

- Every 15 seconds, a worker dies from a work-related accident or disease.
- Every 15 seconds, 160 workers have a work-related accident.
- Every day, 6,300 people die as a result of occupational accidents or work-related diseases.
- Every year, 317 million accidents occur on the job.
- Every year, there are more than 2.3 million deaths per year.
- The annual economic burden is 4% of global Gross Domestic Product.

The World Health Organization statistics for 2008 show that there were nearly 4 million unintentional injury deaths worldwide. The average unintentional fatality rate among all age groups was 59 per 100,000 population. Road traffic accidents were the leading unintentional fatality cause for all age groups under 70.

The globalization of businesses and the interconnection among world economies cause change. Companies and entire industry groups have a growing responsibility to ensure safe practices among their global partners. There are many examples, see the Bangladesh story in Case1-1 that highlights such efforts among retailers.

Another example is the global pressure on the airline industry to improve the overall safety of air travel.[5] During 2012 and 2013, there was a significant drop in airline fatalities below the 10-year average of 750 fatalities. In 2013, there were 29 airline accidents and a record-low 265 fatalities for about 31 million passenger and cargo commercial flights worldwide. In 2012, there were 23 airline accidents and 475 fatalities. Qantas Airline is one of the

CASE 1-1

In April, 2014, a garment factory in the Rana Plaza of Dhaka, Bangladesh, collapsed, killing 1,129 people and injuring 2,515 others. An investigation report blamed the mayor for wrongly granting construction approvals and the owner for bribing local officials for construction permits. It appears that the project used substandard materials and had a blatant disregard for building codes.

The day before, cracks had appeared in the building, shaking the structure. An engineer who then inspected the building declared it unsafe, but factory bosses disregarded the concerns and ordered workers into the building the next morning.

The disaster sparked global responses. New safety standards for garment factories in third world countries and closer involvement in supply chains by major retail companies from the United States and other countries were instigated. Many saw the need for clothing retailers to conduct audits of supplier facilities and safety practices as part of their corporate social responsibilities.

Wal-Mart Stores does business with more than 200 factories in Bangladesh and began inspecting all of them after the April 2013 tragedy. The first 75 audits cost more than $4 million. Wal-Mart found that nearly half of the factories failed the initial safety inspections. One factory was torn down and others faced major changes. Wal-Mart stopped doing business with two of the 75 factories. It employed 10 engineers to regularly inspect factories in Bangladesh and posted the audit results on its website.

safest airlines in the world and has not had a fatal accident since 1951.

The European Aviation Safety Agency (EASA) reported that there were 17 commercial (non-cargo) air transport aircraft accidents in 2013, compared with an average of 27 annually during the last decade.[6] During the same periods, there were 224 fatalities compared to an average of 703. There were no fatal crashes among EASA member companies during 6 million flights in 2013, carrying 800 million passengers.

The US Record

There are at least three major sources of injury, disease, and death statistics in the United States. One is the Centers for Disease Control and Prevention (CDC). Another is the Bureau of Labor Statistics (BLS). These are federal government agencies. A private source is the National Safety Council. In addition, there are many other federal and state agency sources for injury data. Overall, the data show that accidental injuries are significant. After achieving major reductions, there is still an ongoing need to prevent injuries, illnesses, and deaths.

Centers for Disease Control and Prevention (CDC)

CDC has several data collection and analysis resources. An agency within CDC is the National Center for Injury Prevention and Control (NCIPC).[7] Its mission is to prevent violence and injury and reduce their impacts. The agency operates an online database of injury data and statistics called "Web-based Injury Statistics Query and Reporting System" (WISQARS). This is an interactive database system that provides customized reports of injury-related data.

NCIPC data for 2010 include the following:

- 120,859 unintentional injury deaths.
- 26,009 unintentional fall deaths.
- 33,687 vehicle traffic deaths.
- 33,041 unintentional poisoning deaths.
- More than 180,000 total injury deaths each year.
- Injuries are the leading cause of death for people ages 1 through 44.
- About 2.5 million people hospitalized with injuries each year.
- About 31.6 million people treated for injuries in emergency departments each year.
- Violence and injuries cost more than $406 billion annually.

The overall death rate from all causes in 2011 was 807 per 100,000 population. Table 1-1 lists the top ten causes of death in 2011 for the total population, based on death rates.

Bureau of Labor Statistics (BLS) BLS, an agency within the U.S. Department of Labor, compiles work-related injury, illness and death statistics for workers in the United States.[8] BLS refers to this activity as the Injuries, Illnesses and Fatalities (IIF) program. While the Occupational Safety and Health Administration (OSHA) sets rules for work-related injury and illness recordkeeping, BLS compiles information from data submitted by employers. Refer to BLS annual and other reports for detailed statistics on injuries, illnesses, and deaths broken down by age, industry, occupation, injury type, and other factors.

TABLE 1-1 Major Causes of Death in 2011

Cause	Death rate per 100,000
1. Diseases of the heart	191
2. Malignant neoplasms	185
3. Chronic lower respiratory diseases	46
4. Cerebrovascular diseases	41
5. Accidents (unintentional injuries)	39
6. Alzheimer's disease	27
7. Diabetes mellitus	24
8. Influenza and pneumonia	17
9. Nephritis, nephrotic syndrome and nephrosis	15
10. Intentional self-harm (suicide)	12

TABLE 1-2 U.S. Unintentional Injury Deaths for 2009

Class	Number of deaths	Percent of total
All classes	**128,200**	**100**
Motor vehicle	35,900	28.0
Public non-work	34,293	26.7
Work	1,407	1.1
Home	200	0.1
Work	3,582	2.8
Non-motor vehicle	2,175	1.7
Motor vehicle	1,407	1.1
Home	65,200	50.9
Non-motor vehicle	65,000	50.7
Motor vehicle	200	0.1
Public	25,100	19.6

Results for 2012 include 4,693 fatal work injuries, the third lowest since the Census of Fatal Occupational Injuries (CFOI) began in 1992. The overall fatal injury rate in 2012 was 3.5 per 100,000 full-time equivalent workers.

Here are a few facts from the 2012 report about work-related deaths:

- 1,789 were transportation related, with 1,044 occurring on roadways.
- 125 involved aircraft incidents.
- 463 were homicides and 225 suicides.
- 668 died from slips, trips, and falls, with 544 from falls.
- 509 resulted from objects or equipment striking people.
- 838 occurred in construction-related occupations.
- 1,150 occurred in transportation and material moving occupations.
- 224 occurred in protective service occupations.
- 245 occurred in farming, fishing, and forestry occupations.
- 429 occurred in management occupations, with 268 in agricultural business.

National Safety Council (NSC) For several decades, the National Safety Council (NSC) has compiled data on accidents, incidents, injuries, illnesses, and deaths. An annual publication provided detailed analysis of the data. For many years the publication title was *Accident Facts*. More recently, the title is *Injury Facts*. This publication breaks down data and analysis into three groups: occupational, motor vehicle, and home and community. Also the publication now reports information on intentional injuries, such as assaults and self-harm. Data come from a variety of sources.

The U.S. population today is four times larger than in 1903. During the same period, the annual number of unintentional deaths has increased from about 70,000 to more than 120,000. The death rate per 100,000 has decreased from about 90 to about 40. This shows some progress, but much preventive work remains.

Table1-2 shows the NSC-reported unintentional injury deaths information for 2009. The data provide a picture of current performance.

NSC also lists the odds of dying (1 in x odds) from various kinds of causes. Table 1-3 provides a sample of data from 2007 for individuals born in that year.

For 2012, NSC reported information about work-related injuries and illnesses. For example, the top three events leading to injuries, the rate per 100,000 workers and median days away from work include:

- Overexertion and bodily reaction (39.8, 12)
- Slips, trips or falls (27.8, 11)
- Contact with object or equipment (25.5, 5).

Also for 2012, NSC reported the five deadliest industry sectors and death rates per 100,000:

- Agriculture (21.2)
- Mining, quarrying, and oil and gas extraction (15.6)
- Transportation and warehousing (13.3)
- Construction (9.5)
- Wholesale trade (5).

TABLE 1-3 Odds of Dying from Various Causes, 2007

Cause of death	Deaths	One-year odds	Lifetime odds
All external causes	185,067	1,628	2
Heart disease			6
Cancer		7	
Stroke			28
Unintentional injury	123,706	2,436	3
Transport accidents	23,706	6,432	83
Motor vehicle accidents	43,945	5,856	88
Non-transport accidents	76,862	3,920	50
Accidental poisoning			30

Similarly, the five deadliest occupations in 2012 were (along with death rates per 100,000):

- Logging workers (127.8)
- Fishers and related fishing workers (117)
- Aircraft pilots and flight engineers (53.4)
- Roofers (40.5)
- Structural iron and steel workers (37).

The above are samples of injury and death statistics. The aim is to illustrate how well or badly modern society is preventing injuries and deaths. While work-related injury and death rates continue to go down, the need remains to ensure that workers and others return home safely each day.

1-4 IMPACT OF CHANGES

Change is constant. The rate of change appears to be increasing, almost accelerating. There are changes in materials, technology, business practices, societal expectations, and governments and elsewhere. Each of these affects people and the risks they face at work and home as well as in travel and recreation. Not everyone will recognize or understand the changes. Not everyone will learn how to deal with the changes. Not everyone will recognize the risks and foresee how to reduce potential harm.

This section will provide a few examples of challenges for safety and health practice.

Materials Changes

Nanomaterials Nanomaterials have emerged recently as a new class of materials. The hazards associated with them are not well known, but studies are starting to track potential hazards. Nanotechnology in general covers engineered structures, devices, and systems that have a length scale between 1 and 100 nanometers. At this size, materials begin to exhibit unique properties that affect physical, chemical, and biological behavior.

Some nanoparticles may be toxic. Early studies show toxicity varying with various chemical and physical properties. Some nanoparticles can penetrate through the skin or move from the respiratory system to other organs. Research is beginning to understand properties leading to specific health effects. Those involved in protecting workers and other from potential harm from nanomaterials must monitor research results. NIOSH continues to publish guidelines[9] for nanomaterials.

Technology Changes

Glucose Measuring Contact Lens Medical diagnostics methods continue to advance rapidly. On January 17, 2014, Google released information about a contact lens-type device that monitors blood sugar levels in the tears of diabetics once per second. The device contains a miniature transmitter that can relay the results continuously to other equipment. The potential value of the instrumentation is high because of the

CASE 1-2

Up to 7,500 gallons of a chemical, 4-methylcyclohexane methanol, leaked from a 40,000 gallon Freedom Industries Inc. storage tank and surrounding dike into the Elk River in Charleston, West Virginia, in the USA. The tank was about a mile and a half upstream from an inlet for the public drinking water of the city and surrounding communities. The water system supplied about 300,000 people. The chemical is used in coal processing. The brick and concrete dike was failing and needed repair. Officials learned of the spill from odor reports, located the source within hours, and took action.

For days the water supply was not useable for drinking, cooking or washing. Officials quickly told all residents affected, but some experienced skin and other problems before understanding the dangers. Local and state agencies quickly trucked in water and set up distribution points.

After five days, the contaminated river water had moved downstream and become diluted. Sampling showed the contaminant levels were below toxic levels or there was no contaminant. The water company then began a process of flushing supply pipes and allowing customers to flush their water pipes to remove any contaminated water. The flushing protocol took several days to avoid excess demand on the supply system. Weeks later, many individuals claimed that risks and resulting health conditions remained. Many people did not trust the public water supply for some time.

Initial studies determined that the facility had not received any inspections from federal or state environmental agencies for years. The chemical was not very hazardous. There were few inspectors and they focused on more hazardous sites. Freedom Industries Inc. had purchased the facility about a month before the spill. Within days of the spill, Freedom Industries filed for bankruptcy.

A few weeks later the federal Centers for Disease Control and Preventions reported that a second chemical made up 5 percent of the contents of the leaking tank. It was polyglycol ethers, PPH, less hazardous than the main chemical.

large and growing number of diabetic patients. Studies will define the hazards for wearers.

Flexible Silicon Patches Researchers have created very thin sheets of silicon that incorporate electronic sensors and circuits. They are flexible and attachable to human skin. They can monitor a range of functions and send information to other equipment.

Wearable Electronics A highlight of the 2014 Consumer Electronic Show was "wearable electronics." One example is the computerized display glasses that present visuals just above the normal eye viewing field. The eyeglasses have a display, camera and computer. The model for the show also handled voice commands from the wearer.

Another wearable device is a smart watch. It handles most of the display and computer applications available for smart phones, but only in a smaller package wearable on a wrist. Newer models will add GPS technology and new kinds of applications. These new technologies may have major applications for safety and health. The devices can help track the physical locations of employees, especially if working in hazardous situations. Potentially, the devices can monitor exposures and warn the wearer of pending danger. The devices can make communication with or between workers easy, using hands-free operation. Monitoring patches and wearable electronics can be a major help for certain safety and health functions.

Driverless Vehicles Another highlight of the 2014 Consumer Electronics Show was the expansion of driverless automobile features. A new term is "autonomous car." A vehicle may operate as a robot using remote control similar to flying drone airplanes. It can automatically maneuver from one location to another in traffic. A vehicle may supplement the limitations of drivers by taking over operations in difficult and frustrating conditions. Audi has produced a Piloted Driving vehicle with front and rear laser to see and monitor traffic and cameras to monitor lane traffic. In addition, the State of Nevada issued a special motor vehicle license to test the autonomous car in real traffic. Such vehicles may help to reduce the high rate of vehicle accidents and resulting injuries and deaths. Such vehicles may allow the operation of vehicles in dangerous off-road mining and materials-handling functions.

Automated Aircraft On July 6, 2013, an Asiana airplane landing at the San Francisco International Airport approached short of the runway. The tail of the plane caught the seawall that extends from the San Francisco Bay water to the end of the runway. With 307 people on board, the plane tumbled and skidded to a stop. Fire trucks sprayed foam extinguishing agent on the emerging flames. In the process the trucks struck two passengers who had been thrown from the plane during the crash. A third passenger died in hospital. Preliminary investigations revealed that the pilot flying the plane had never manually landed a plane of this classification. On this flight an instructor pilot oversaw the work of the pilot.

Part of the problem is that the instrument landing system for that runway was shut down for maintenance. The airport had published the shut-down well in advance through standard aviation channels covering special notices.

Another part of the problem was that large commercial aircraft fly using computer control of the aircraft. Before departure, the crew enters the flight path information onto the airplane computers covering the departure and arrival airports. With automated landing systems, pilots are hands-free.

In addition, preliminary investigations identified that the aircraft's pilot was not trained in manual landing. He was taught how to fly using automated management. The investigation uncovered information that many commercial pilots no longer have experience landing large aircraft manually. Thus, a backup measure may not exist for automated landing systems.

3-D Printing 3-D printing is expanding rapidly as capabilities expand and prices drop. 3-D printers are even available at reasonable prices for home use. 3-D printing allows someone to create an object of any shape with 3-D software and have the object created by a printer. The process often uses a layering approach to build a desired object one thin layer at a time. An object with voids becomes easy to make. The most common medium is plastic. However, 3-D printing with metals is also expanding. There is also 3-D printing of biological materials and creation of artificial tissue that may be replacement organs some day. A safety and health challenge is managing the materials and production of items. Each may have varying degrees of hazards because of the production materials, the size and movement of the printer and its parts, and the hazards of the items produced.

Business Practice Changes

Safety Management Systems (SMS) One of the growing safety strategies is safety management systems. The idea uses an organized process to get an entire company or organization involved in implementing safe practices and achieving effective business and safety goals. The process includes identifying and recognizing hazards and implementing changes to increase safety effectiveness.

Commercial aviation provides an example. International guidelines define how the complexities of aviation operations help achieve safety for employees and travelers. The International Civil Aviation Organization (ICAO) publishes a wide range of standards related to aviation, including aircraft, pilots, operations, and other elements of aviation. The standards include safety management. A recent ICAO

publication[10] spells out the requirements for aviation safety management systems.

International maritime shipping offers another use of safety management systems. The International Maritime Organization publishes the International Safety Management Code.[11] It prescribes a safety management system.

Part V of this book addresses managing safety and health, including safety management systems.

Risk Analysis and Management Strategies Using risk analysis and management is growing in the United States. Chapter 34 addresses risk analysis and risk management in detail.

Many in the safety and health field are familiar with risk management from an insurance perspective. The growth in risk management as a strategy for controlling hazards stems in part from countries outside the United States. It represents a change in approach.

To a great extent, laws, regulations, and standards drive safety and health practices in the United States. It is a *prescriptive* approach. Standards and regulations prescribe how to achieve safety, and enforcement focuses on compliance with the standards and regulations.

A different approach emerged some time ago from legislative action in the United Kingdom and this has spread to other Commonwealth and European countries. Chapters 5 and 34 provide more details. The concept requires employers, manufacturers and others to identify and evaluate the risks of their workplaces, products, and processes. They must then act to eliminate, reduce, and control the risks. Governments do not have to prescribe in detail how to achieve safety through standards and regulations. This is a *performance* approach. Enforcement focuses on how well responsible parties can identify and mitigate risks.

Many employers and manufacturers in the United States will use both approaches concurrently. The latter emphasizes a comprehensive analysis of hazards and a clear definition of which controls should be in place. Prescriptive standards and regulations may not always cover the unique situations of specific employers, manufacturers, and processes.

Societal Expectations

Most people do not understand the technologies they use every day and the associated risks. They depend on designers, producers, government agencies and others to protect them from potential harm. If there is public fear and increased knowledge about a hazard, special interest groups may advocate for better protection. Otherwise, there may be little public input.

Over the years, there are many examples of changes that have stimulated public pressure for actions at many levels. Here are just a few examples:

- The industrial revolution created a public outcry for greater protection of workers. The famous novel by Upton Sinclair, *The Jungle*, was one publication that had significant influence on increased safety for workers. Changes in manufacturing occurred in most developed countries. However, as the story about clothing manufacturing in Bangladesh (Case1-1) shows, dangers from the industrial revolution are still present.
- An increased focus on protecting the environment resulted from the book by Rachel Carson, *Silent Spring*. In the 1960s and earlier, engineering education often referred to materials that remained after achieving a desired product as "byproducts." Companies considered most byproducts as waste. Public pressure has changed how engineers handle the excess materials used in production.
- With the expansion of nuclear power throughout the United States after WWII through the "Atoms for Peace" program, the public felt a concern for risks from radiation. One result was the creation of a federal agency to oversee the safety of nuclear power plants (the Nuclear Regulatory Commission). It became separate from the agency promoting and overseeing nuclear energy, now part of the U.S. Department of Energy. Later nuclear disasters at Three Mile Island, Pennsylvania, and Chernobyl, in Ukraine, increased public concerns about radiation.
- The chemical leaks at Love Canal near Niagara Falls, NY, gained a lot of national media attention. That led to a public outcry to clean up chemical waste sites, and the creation of the federal "Superfund." A national cleanup program for hazardous waste sites resulted.
- In 1989, there was an "Alar Scare." Alar is a chemical used in the apple industry. The U.S. Department of Agriculture, responsible for agricultural safety and health, approved the use of the chemical. Later, studies suggested that it was a carcinogen. The public outcry led to litigation. The courts ruled Alar as unacceptable.
- Today, an agricultural issue involves DNA-altered, genetically engineered food crops. Some countries have banned such products from their markets. Using biology to alter crops to increase yield, improve product handling and shelf life and to add desirable properties is a relatively new area of science. Cross-breeding of plants to gain desirable properties has been practiced for decades. By using DNA modifications, the change process is faster and offers more choices. However, we know little about the long-term effects of genetically engineered plant development procedures. Thus, there is public concern.

Government Changes

Various levels of governments have responsibilities to protect the safety, health, and welfare of its citizens. The responsibility varies with each level of government. Included are setting regulations, enforcing the regulations, and responding to dangerous situations.

Enforcement Resources and Division of Responsibilities The 2013 chemical spill in the Elk River near Charleston, West Virginia (Case1-2), illustrates some difficulties for governments and potential gaps in responsibilities. According to reports, the storage facility did not fall under a special emphasis program of OSHA, so that agency did not inspect it. The material was not an official "hazardous materials" of the U.S. Environmental Protection Agency. As a result, the West Virginia Department of Environmental Protection did not inspect the site due to limited inspection staff. Because the site was only a storage site and no longer manufactured chemicals, it did not need permits to discharge pollutants into the air or water. The state last visited the site in 1991 when it was a refinery operated by an earlier owner. The West Virginia American Water company, which took water from the river to supply the area, learned of a problem after receiving odor complaints.

Community Burden For some communities, the protection of its citizens is an overwhelming burden. Consider the challenge to first responders in small communities. The railroad created many small towns in the nineteenth century. They needed goods to haul. Some with mainlines will have 100,000 or more rail cars containing hazardous materials traveling through every year. Should there be a derailment or other incident involving a leaking car, the local volunteer fire department as a first responder must be able to identify the material released. Firefighters must wear appropriate protective clothing during a response. Many communities do not have the money to buy all the possible protective clothing necessary for each class of hazardous material.

1-5 DESIGNING TO ACHIEVE SAFETY

Prevention through Design is a movement that seeks to emphasize engineering design to eliminate or reduce hazards. Designs may involve structures and building materials that simplify construction or make the construction sequences safer. They may seek to prevent structural failure. Designs may involve changes to machines and equipment. Designs may involve new or revised processes. The concept has been around for a long time. It has been adopted once more as a theme for safety and health.

Engineering Revision

In 1925, the National Safety Council's College Committee gave a report at the Annual Congress. The title of the report was "Accident Prevention and the Engineer." The report focused on two ways to prevent accidents: education and the elimination of hazards. The report stated that the two go hand in hand and are inseparable. The authors described two approaches to eliminate hazards. One involved "safeguards" that are accessory devices and not integral parts of machines themselves.

The second approach was *engineering revision*. Engineering revision involves redesigning operations, processes, and equipment to eliminate or reduce hazards. Engineering revision goes beyond education and the application of safeguards. Engineering revision is the same concept as prevention through design.

The presentation continued by challenging engineering colleges to include safety in design courses of all engineering disciplines. The challenge came from a report of the Safety Committee of the Society for the Promotion of Engineering Education.

Prevention through Design (PtD)

One primary role for engineers in achieving safety is *prevention*. The role requires recognition of hazards and applying designs that eliminate and reduce hazards. This focus on designing for safety has increased in the last decade or so.

Why is this significant? The concept teaches engineers the primary responsibility they have in design as stated in codes of ethics. One impetus resulted from the 2007 National Institute for Occupational Safety and Health (NIOSH) workshop on "Prevention through Design." NIOSH now refers to this emphasis program with an acronym, PtD.[12]

The NIOSH symposium followed an earlier conference in 1998 that led to a book on the topic.[13] In 2011, the American Society of Safety Engineers published a standard on Prevention through Design.[14] ASSE and NIOSH conducted a symposium on the issue in 2011.[15]

Somehow the importance of safety through engineering design had lost visibility over the years. Today, the report of 1925 has regained momentum and attention under Prevention through Design (PtD). Engineering design continues to play a very important role in protecting people, property and the environment.

EXERCISES

1. Find out which countries have high life expectancies. Which have low life expectancies?

2. Find out the values government agencies, state workers' compensation standards, insurance companies or organizations and legal associations place on human life.
3. Obtain the code of ethics from several professional groups. Identify what importance each places on protecting people, property, and the environment.
4. Obtain information on the American Chemical Society "Responsible Care" program. Identify which features help assure safe management of dangerous chemicals for workers and for communities.
5. Obtain the Corporate Social Responsibility statements and action plans of several corporations. Complete a comparative analysis of them to identify the importance placed on safety and health.
6. Obtain examples of company sustainability statements. Visit the website for the Center for Safety and Health Sustainability. Determine if company statements include a focus on safety and health.
7. Identify some "standards of practice" in individual engineering fields for specific hazards and their controls. Talk to craftsmen to see what standards of practice they use in certain tasks to prevent injuries.
8. Locate the injury and death statistics published by the Bureau of Labor Statistics, the CDC, and the National Safety Council for the last four years. Discuss the significant findings and trends found in these statistical sources.
9. Identify technological, business, and government changes and their potential impact on safety and health. Consider the hazards introduced, the user knowledge requirements for effective use of the changes, and new kinds of controls needed.
10. Monitor three freight trains containing tank cars. Record the placard number appearing on each car. From government placarding standards, identify what the contents are for each car. Discuss the risks for each type of contents for a community should there be a derailment and resulting leaking cars.

REVIEW QUESTIONS

1. How many chemical substances does the *CAS Registry* contain today? How many are in use?
2. What are the three main reasons for safety? Give examples for each of the three reasons.
3. Which organization introduced the "Responsible Care" program?
4. What is CSR?
5. What are the three main elements of sustainability? Which element encompasses safety and health?
6. Name sources for unintentional injury statistics:
   (a) Worldwide.
   (b) In the United States.
7. How many unintentional injury deaths occur each year in the United States? Which of the following categories has the most? The least?
   (a) work
   (b) home
   (c) vehicles
   (d) recreation
8. What is the approximate annual cost of injuries in the United States? Worldwide?
9. What are two of the five deadliest industry sectors? Two of the deadliest occupations?
10. Describe nanomaterials and their potential impact on safety and health.
11. Which federal agency is the best source of research information on the impact of nanomaterials on safety and health?
12. Explain the basic difference between a prescriptive approach to safety and health regulation and a performance approach.
13. What is "engineering revision?"
14. Explain "Prevention through Design" (PtD). Which organizations have conducted symposiums on this topic?

NOTES

1 *CAS Registry*, Chemical Abstract Service, a Division of the American Chemical Society, Columbus, OH, updated daily.

2 www.nspe.org/resources/ethics/code-ethics

3 www.centershs.org/

4 www.ilo.org

5 www.airlineratings.com

6 http://easa.europa.eu/communications/docs/annual-safety-review/2013/EASA-Annual-Safety-Review-2013.pdf

7 www.cdc.gov/injury/index.html

8 ww.bls.gov/iif/

9 U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational

Safety and Health, *Current Strategies for Engineering Controls in Nanomaterial Production and Downstream Handling Processes*, Cincinnati, OH, DHHS (NIOSH) Publication No. 2014–102, November 2014.

10 *Safety Management Manual*, Document 9859, 2nd ed., ICAO, Montreal, Quebec, 2009.

11 www.imo.org/OurWork/HumanElement/SafetyManagement/Pages/ISMCode.aspx

12 www.cdc.gov/niosh/topics/ptd/

13 Wayne C. Christensen and Fred A. Manuele, *Safety through Design*, Washington, DC, National Safety Council, 1999.

14 ANSI/ASSE Z590.3-2011, *Prevention through Design: Guidelines for Addressing Occupational Risks in Design and Redesign Processes*, 2011.

15 www.asse.org/professionalaffairs_new/ptd.php

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Sinclair, U. *The Jungle*, Doubleday, New York, 1906.

CHAPTER 2

SAFETY AND HEALTH PROFESSIONS

2-1 INTRODUCTION

Many disciplines contribute to keeping people safe. Over the years, engineers have done a lot to further this effort and so have other professions. This chapter will explore the different roles that various professions adopt in achieving safety. Very often, people from different disciplines must work together for safety. Together they identify hazards, develop effective solutions to safety problems and achieve safe operations, products, buildings, and systems.

No one person can be an expert in everything, especially in today's fast-paced, high technology society. It is difficult to stay up to date with all the laws and regulations at federal, state, and local levels that impact safety. One would have to be an expert in engineering, law, technology, processes, behavioral science, training and education, health sciences, finance, insurance, management, and other fields.

Safety practitioners may function as generalists or specialists. Generalists use a range of knowledge and often work together with specialists in other knowledge areas. Generalists provide leadership in applying safety principles to specific safety problems. Specialists use their unique knowledge and skills to help understand and resolve complex safety issues. They provide insights and methods that generalists may know about.

There is an interesting attribute of people who work in safety and health. They have a very high rate of job satisfaction. Several studies in the United States and other countries noted job satisfaction ratings of 90% or higher. Even with a wide range of job duties and the need for a broad range of knowledge, working in safety and health is highly satisfying. Some practitioners report satisfaction because they saved people's lives and sent workers home safely. Others find satisfaction from the fact that their work is never the same every day.

Moving Safety Deep into Organizations

Safety specialists cannot achieve safety on their own. Achieving safety requires participation by workers, supervisors, managers, and others. Safety will not be effective when work groups refer safety issues and defer responsibility to a safety specialist or safety department. The work groups must participate in hazard recognition and control. As a result, many employers and unions have moved safety deeper into their organizations and into work groups themselves.

Many employers engage people at all levels of their organizations to achieve safety. They focus especially on work group leaders and supervisors. Many provide training so work group leaders and supervisors can recognize the hazards of their work. Training includes methods and procedures to eliminate and reduce hazards and prevent injuries. Training develops leadership skills that help gain the participation of all the workers on a team or in a work group.

Some employers give recognition to leaders who complete training and safety programs. Hard hat color or emblems are used to indicate a safety learning milestone. Other forms of recognition are used that help build a culture that places safety high in job performance. Work groups are scored on various safety performance metrics and employers publicize their achievements.

Safety and Health Job Outlook

The U.S. Department of Labor's Bureau of Labor Statistics (BLS) annually evaluates a wide range of jobs and positions. BLS publishes the information in the *Occupational Outlook Handbook*.[1] Table 2-1 lists the publication's positions related to safety, health and environment and the 2012–2022 job outlook. For each position, the publication identifies current salaries and lists educational qualifications, job functions, and other information.

2-2 SAFETY PROFESSIONALS AND PRACTITIONERS

A safety professional is someone who has the knowledge and skill to advise employers about eliminating and reducing hazards by applying appropriate controls. For many years the

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 2-1

For several years, the Green Bay Packers football team in the USA were dismal to mediocre. Then, in 1959, a new coach arrived by the name of Vince Lombardi. He set standards for American football that became legendary and inspiring for many outside football. Perhaps his most quoted saying is, "Winning isn't everything, it's the only thing." His standards inspired excellence and teamwork over individual performance. As he said, "It's all about teamwork."

Upon his arrival in Green Bay, he held his first meeting with team members. He changed the culture by stating their mission. "I'm not remotely interested in being just good. We are going to relentlessly chase perfection, knowing full well that we won't catch it, because nobody is perfect. But we're going to relentlessly chase it, because in the process, we will catch excellence."

It is this kind of desire that people engaged in safety and health use to become excellent safety and health practitioners. It leads them to engage others in a team effort. For most, it is all about leadership and keeping people safe.

TABLE 2-1 BLS Safety and Health Positions and Job Outlooks

Position	2012–2022 Job outlook (%)
Occupational Health and Safety Specialists	7 (Slower than average)
Occupational Health and Safety Technicians	11 (As fast as average)
Health and Safety Engineers	11 (As fast as average)
Environmental Scientists and Specialists	15 (Faster than average)
Environmental Science and Protection Technicians	19 (Faster than average)
Hazardous Materials Removal Workers	14 (As fast as average)

American Society of Safety Engineers (ASSE) has maintained a definition of professional safety practice. The current definition[2] appears in a voluntary standard available from the Society.

The primary roles of safety professionals are anticipating and recognizing hazards, identifying controls for them, and recommending protective action to managers. They also establish and operate management systems to achieve the safety of workplaces, operations, equipment, facilities, products, and processes.

The role of a safety professional is broad. It requires knowledge of many different areas. The breadth of required knowledge has expanded over the years. Table 2-2 lists areas of knowledge and the proportion of safety professionals with responsibility for each area.

The domains of knowledge for safety professionals are not static, but are continually changing. Changes have broadened responsibilities, not reduced them. One example involves impacts following the 9/11 destruction of the World Trade Center in 2001. Most companies have increased attention to security. In some cases, safety professionals find elements of security now as part of their job description.

Many safety professionals belong to the American Society of Safety Engineers. Its membership data identify

TABLE 2-2 Safety Professional Job Responsibilities[a]

Area of Practice	Percent with Responsibility
Safety	88.7
Industrial hygiene	65.9
Ergonomics	59.4
Risk management	53.2
Fire protection	51.4
Safety engineering	50.0
Environment – general	41.9
Occupational health	43.7
Hazardous materials management	40.6
Environmental health	23.0
Systems safety	22.9
Security	20.5
Product safety	17.0
Environmental engineering	11.8
Engineering	10.8
Public health	10.3
Health physics	9.8
Medical	8.6
Nursing	3.4
Other	10.0

[a]Roger L. Brauer, *Career Success: Lessons Learned from a New CSP Salary and Demographic Survey*, Presentation No. 551, Proceedings, American Society of Safety Engineers Professional Development Conference, June 2008.

educational preparation. More than 90% of members have Bachelor's or higher degrees. One third to one half have advanced degrees. ASSE salary studies show a major increase in the average level of education during the past two decades.

Convergence of Safety, Health and Environmental Practice

In 1970 when Congress created several federal agencies for safety, health and environment, each specialty stood somewhat alone. There were separate educational programs for safety, industrial hygiene, health physics, fire protection, and environmental science. Today, the specialties have

converged to a great extent. That created positions and opportunities for generalists, cross-trained in multiple areas, and the need for specialists remains.

Safety professionals often have to be generalists to undertake the tasks involved in their positions. Many organizations have combined various safety-related functions into one organizational unit. Some still have specialized positions and some contract for specialized services. Consider a smaller company that has only one position devoted to safety, health and environmental matters. A person filling the position must have knowledge in all three or even more areas to manage the role effectively.

In large companies there are opportunities for specialized positions. If an organization combines safety, health, and environment in one department, the person at the top must be conversant in all areas. Such positions do not require high levels of expertise, but enough knowledge to lead the combined areas. Recently, the convergence has gone even further to incorporate risk analysis and risk management and other safety-related roles.

Specialty Practices

There are several specialties within safety practice; some are industry-specific safety specialists and others are linked to particular fields, such as biology.

One example is *system safety*. This specialty resulted from a need to identify hazards and potential failures in military and high technology systems and equipment. The specialty developed a number of methods that will be discussed in Part V. The membership organization for this specialty is the International System Safety Society.

Another example involves people who focus on the management methods used to achieve successful safety practice in an organization. Some refer to this specialty as safety management. Part V covers some of these methods in detail. The membership organization is the International Safety Management Society.

International Practice

Those serving as safety professionals in other countries have similar roles to those professionals working in the United States. Table 2-3[3] lists the functions performed by similar practitioners in 13 countries, mostly European countries. Overall, participation in the functions is similar across borders. When one looks at further details in this study, the similarities and differences are clearer.

One of the factors that influences differences in practice across countries is the person to whom safety professionals report. In the U.S., many report to operational or functional top management units headed by non-safety professionals. In Europe, many safety professionals report to a physician.

2-3 ENGINEERING

Engineers have always played a prominent role in advancing safety and improving safety performance. With the industrial revolution and its extension into the early 1900s, major hazards involved machines, power, and losses from fires. There were no college programs that trained professionals for safety practice. Insurance companies covering industrial

TABLE 2-3 General Comparison of Practice in Several Countries

Topic	Austria	Australia	Finland	Germany	Italy	Netherlands	Norway	Poland	Portugal	Singapore	Switzerland	United Kingdom	United States
TASK (by Group)													
Problem identification & analysis	75	79	58	72	77	73	65	63	79	72	77	80	87
Develop & implement solutions	71	72	59	72	63	68	52	59	68	76	71	79	77
Training, information & communications	75	80	63	77	76	69	63	78	70	80	79	82	81
Inspection and research	63	69	55	75	57	68	54	69	58	75	69	74	75
Emergency procedures and settlement of damage	43	39	30	47	48	32	29	40	40	50	37	40	41
Regulatory tasks	10	23	22	15	13	13	15	17	31	21	18	25	24
Knowledge management	67	72	52	64	62	68	67	54	75	75	72	73	75
Management & Financial	47	55	44	52	50	55	52	55	54	57	60	63	69
HAZARDS	72	74	67	77	59	64	54	50	54	54	69	76	72
CONTACTS													
Internal	64	71	64	71	70	72	60	69	54	58	68	70	75
External	43	61	53	54	58	51	58	41	46	55	52	63	61

Note: Values listed are the percent of responses by country.

losses hired engineers because of their technical knowledge. They used them to help reduce insurance claims and improve the safety performance of clients. *Safety engineer* is the term for that position that emerged. Many engineering colleges responded to the need. For example, in 1941, over 100 engineering colleges introduced courses in industrial accident prevention.[4]

An important role in reducing hazards and potential accidents and incidents was inspecting facilities, equipment, and operations. Inspectors identified dangers and recommended controls to eliminate or reduce the dangers. During the first half of the twentieth century, *factory inspector* was the title for many in these positions but there were also other job titles.

The two roles were not always distinct and neither were the job titles. Some engineers conducted inspections, even as they do today with their specialized knowledge. A newer term for persons checking on compliance is *auditor*. As a result, some safety engineers were engineers by training and others were not. Even today, compliance may involve engineers (see Case 1-1).

The confusion and evolution of job titles for people devoted to safety continue. The term safety engineer often refers to someone more accurately defined as a *safety professional*. From the early history of safety practitioners arose the American Society of Safety Engineers. Today only about 15% of its members hold academic degrees in engineering. At times members considered name changes for the organization, but there was no agreement on a different title for practitioners.

Safety Engineering

Safety engineering is the application of scientific and engineering knowledge, principles and methods to identify and eliminate or reduce and control hazards. Safety engineers need to know a lot about other engineering fields. They often work together with engineers from other specialties. Their roles are similar to those of safety professionals. In addition, they participate or coordinate with designers and others in non-engineering disciplines.

Fire Protection Engineering

Fire protection engineering is an engineering specialty focused on preventing and reducing loss of life and property from fires, explosions, and related hazards. Fire protection engineers specialize in fire prevention, protection, detection, and alarms. They plan and design fire control and extinguishment systems for structures, equipment, processes, and systems. They also design egress routes to allow safe exiting from fires and related incidents.

There are also fire protection specialists. They do not have degrees in engineering or fire protection engineering, but have developed extensive knowledge about fire hazards and their control. The professional membership organization for fire protection engineers and specialists is the Society of Fire Protection Engineers (SFPE).

Chemical Engineering

Chemical engineering involves planning and designing processes and equipment for chemicals. Because many chemicals are hazardous materials and many processes involve heat and flammable materials, chemical engineering education includes some focus on safety. The professional organization in the United States is the American Institute of Chemical Engineers (AIChE). It also operates the Center for Chemical Process Safety (CCPS).

Civil Engineering

Civil engineering covers the design of public facilities: buildings, roads, bridges, dams, water and waste management plants and piping. Civil engineers ensure that such facilities are structurally sound and earthquake-resistant, and prevent exposure of the public to dangerous conditions. They contribute to transportation safety of automobiles, trucks, trains and pipelines. The longstanding professional organization for civil engineering in the United States is the American Society of Civil Engineers (ASCE).

Mechanical Engineering

Mechanical engineering covers the design of machines, boilers and pressure vessels, elevators, and manufacturing processes. Since the beginning of the industrial revolution, mechanical engineers have been engaged in protecting workers and consumers from dangers of equipment and processes. They also help set safety standards. The primary professional organization in the United States is the American Society of Mechanical Engineers (ASME).

Electrical Engineering

Electrical engineering handles the design and operation of electrical power generation and distribution systems. It contributes to the design and operations of electrically powered equipment and vehicles. Electrical and electronic engineers work on a range of communication systems involving electromagnetic energy. Electrical engineers have developed a range of safety devices and circuits to eliminate and reduce electrical hazards for workers and consumers. Their primary professional organization is the Institute of Electrical and Electronic Engineers (IEEE).

Industrial Engineering

Industrial engineering deals with processes and operations with a strong emphasis on efficiency, productivity, and cost containment. Industrial engineers organize work and help to make work environments safe. They often receive training in human performance topics, such as safety and ergonomics. Their professional organization is the Institute of Industrial Engineers (IIE).

2-4 HEALTH SCIENCES

The well-known specialties in health sciences are medicine and nursing. Health sciences focus on disease, illnesses, and injuries. There are also lesser-known specialties. Epidemiologists study disease patterns and transmittal. Toxicologists study the effects of exposure to materials. Some health science specialties are closely involved in illnesses, injuries, and potential death from incidents and accidents.

Industrial Hygiene

Industrial hygiene specializes in the anticipation, recognition, prevention, and control of hazards leading to illnesses and diseases. Industrial hygienists specialize in measuring chemical and physical environment exposures. They specialize in preventing such exposures, especially harmful exposures. They advise management on the dangers of such hazards and implementing appropriate controls. The expansion of electronic instrumentation and automated analysis technologies has slowed the demand for industrial hygienists. The two main professional organizations in the United States are the American Industrial Hygiene Association (AIHA) and the American Conference of Governmental Industrial Hygienists (ACGIH). The latter is the primary source of exposure standards related to occupational illnesses.

Health Physics

Health physics specializes in recognition, prevention, and control of radiation hazards. The hazards involve both ionizing and non-ionizing radiation. Health physics is a small branch of medical physics. Their professional organization is the Health Physics Society (HPS).

Occupational and Environmental Medicine

Occupational and environmental medicine is a branch of medical practice specializing in disease and illness related to work and environmental exposures. Occupational health physicians diagnose and treat diseases and illness that may arise from work and exposure to hazardous environments. Such exposure may be a contributory factor in other diseases. Treatment may include various physical and occupational therapies to allow a return to work. Occupational health physicians also promote healthy workplaces and deal with workplace stresses. The professional organization in the United State is the American College of Occupational and Environmental Medicine (ACOEM).

Occupational Health Nursing

Closely associated with occupational and environmental medicine is occupational health nursing. Occupational health nurses deal with diseases and illness related to work and environmental exposures. They help manage cases for employers to accelerate a return to work. They help employers deal with work-related injuries and illness. They handle preventive programs such as immunizations and worker wellness promotion. The professional organization in the United States is the American Association of Occupational Health Nurses (AAOHN).

2-5 MANAGEMENT SCIENCES

Some people involved in safety and health practice come from business and management educational backgrounds.

Risk Management

Risk management seeks to identify and reduce all types of losses either completely or to an acceptable level at the lowest possible cost. Some organizations have risk managers, who analyze potential losses, such as financial losses and fire, weather, operations, security, legal, and other losses. They often purchase insurance to transfer potential losses. They work for banks, insurance companies, hospitals, health care facilities, and other businesses. They may also work with safety and health specialists on preventive strategies and approaches.

The methods of risk management are now an important part of the safety and health field. Other chapters in this book will discuss those methods.

A professional organization devoted to risk management is the Risk Management Society (RIMS). The acronym reflects the former name of the organization, Risk and Insurance Management Society.

Loss Control

Some insurance companies have business opportunities that insure employers and others against accidents and incidents involving people, property and the environment. A significant kind of insurance is workers' compensation, discussed in Chapter 6. To reduce claims, insurance companies created services to help their clients reduce accidents and incidents leading to claims, this is called "loss control." The function involves studying the frequency and severity of claims and how they came about. Loss control specialists use the results to advise clients on ways to avoid those events. The professional organization is the Insurance Loss Control Association (ILCA).

Human Resources

Human Resources (HR) involves a wide range of programs and functions of an employer related to recruiting, hiring, paying, and supporting employees. In some cases, safety and health functions report to the manager of Human Resources.

Human Resource managers often deal with workers' compensation and other insurance. They may oversee return-to-work programs following illness and injury. Overall, safety and health functions are a small, but important, element of Human Resources. The professional organization is the Society for Human Resource Management.

2-6 BEHAVIORAL SCIENCES AND EDUCATION

The safety and health field involves people. As a result, there is a need for knowledge of human behavior and learning. Human behavior and learning are critical to safety and health performance.

Psychology

In general, psychology is the study of individual behavior. Sociology deals more with group behavior. Psychology has many areas of specialization. A few psychologists become involved with preventing accidents and incidents leading to injury, illness and death. Many refer to this specialty as behavior-based safety. Psychologists have developed techniques to measure and influence safe attitudes and behaviors.

Adult and Continuing Education

Education and training have been a major part of safety and health. Early safety proponents pressed for education and training for workers so they could do their jobs effectively and safely. Many turn-of-the-century factories had workers who spoke a variety of languages. That made training for job tasks and safety difficult because leaders did not speak the languages of the workers. In some regions of the United States today, having a common language among workers remains a training issue.

Education specialists know that different people learn differently. Some focus on adult learning, since most workers are adults. With technology and other changes there is always something new to learn. Education specialists in safety and health help people to deal with job tasks and change. The specialized organization for trainers is the National Association for Environmental Safety and Health Trainers (NESHTA).

2-7 THE LEGAL PROFESSION

Nearly every endeavor hinges on some aspect of the law. As a result, lawyers often become involved in safety and health matters, such as writing and interpreting laws, regulations and standards. Some deal with compensation for injuries, illnesses, and deaths or are involved in litigation related to safety of products and workplaces.

2-8 OTHER PROFESSIONS

There are other professionals who work in safety.

Ergonomics

Ergonomics is the science of work. The goal of ergonomics is to achieve human performance, safety and satisfaction. Ergonomists seek to improve the fit between people and their equipment, environments, systems, workplaces, and information. Ergonomists seek to reduce task errors and physical stress. Ergonomics has a strong emphasis on the physiological and biomechanical aspects of human performance. Some in this field prefer the term human factors specialist or human factors engineer over ergonomics. The term human factors emphasizes the behavioral and cognitive aspects of performance, safety, and satisfaction. Ergonomists and human factors specialists often receive an education in psychology, but some come from engineering, industrial hygiene, and safety academic programs. The professional organization for this field is the Human Factors and Ergonomics Society (HFES).

Architecture

Architecture involves the design of buildings and other facilities. They may be public buildings or have private owners. Architects work closely with civil and structural engineers to prevent untimely building failure or collapse, such as in earthquakes. They work with fire protection engineers to meet life safety and other fire protection standards. They consider safety when selecting materials for walking and working surfaces. They may plan design features to make maintenance work easy and safe. They plan for safety of entries, building circulation and workstations. They design heating, cooling, lighting, and other building systems for the convenience and comfort of occupants.

Urban Planning

Urban planning deals with the organization and layout of areas of land and complexes of buildings. Urban planners help craft zoning ordinances and regulations to remove community-level hazards and assure effective and safe traffic. They seek to avoid congestion, noise, and environmental hazards for communities. They may participate in developing emergency response planning for communities.

Security

There are many kinds of security. They range from security related to confidentiality of business information and electronic communications to physical security at local, regional, national and international levels. Security involves identification and

analysis of threats. It includes planning, design, and implementation of features that prevent criminal damage or violent crimes.

Some security specialists become involved in issues that also affect safety and health for people in buildings and communities. The threats may overlap with the domains of safety professionals, such as fire, explosion, power interruption, physical damage, injury, illness, and death. As a result, the work of some safety and health specialists now includes security and working closely with security specialists.

2-9 EDUCATION FOR SAFETY PROFESSIONALS

Most professionals engaged in the prevention of accidents and incidents have college and university degrees. Some have associate degrees. Most have a Bachelor's degree and many have advanced degrees. The breadth of knowledge and skills required to work in the safety field drives the need for comprehensive education.

The number of academic programs offering specialization in safety and health fields continues to grow slowly. The American Society of Safety Engineers maintains on its web site a database[5] of safety and related academic programs in the United States.

Educational Quality Standards

Higher education seeks to assure its students that academic programs have quality. For some time, obtaining a quick academic credential has created a challenge for buyers of education. With the growth of the Internet and online educational programs, the challenge has grown. Employers, governments, and individuals want assurance that degrees and diplomas are valid.

The United States There are ways to identify the quality of colleges and universities and some of their programs in the United States. One way is to refer to the recognition from the U.S. Department of Education.[6] Another is to identify accreditation from a private, national accreditation organization approved by the Council for Higher Education Accreditation (CHEA).[7] The two organizations often work together to help the public check on the quality of higher education institutions.

CHEA sets standards for higher education academic accreditation. Specific accrediting bodies seek recognition from CHEA and accredit schools or programs. The CHEA databases include both institutional and program accreditations. ABET, Inc. is one program-accrediting body that handles safety, industrial hygiene, and related programs.

There are also ways to identify unrecognized accrediting agencies, unaccredited schools and schools that are considered diploma mills. The U.S. Department of Education is one source[8] and CHEA[9] is another.

Some states have made it illegal or have restricted use of degrees from unaccredited schools or diploma mills. A few states maintain a list of unacceptable schools. CHEA offers information about individual state regulations.

Outside the United States Understanding higher education outside of the United States is complex and confusing. Most other countries do not have a system of higher education accreditation like that used in the United States. In some countries, a government agency, such as a Ministry of Education, identifies which schools are legitimate.

Not all higher education credentials have the same names as found in the United States. Typical U.S. terms are associate, bachelor's, master's, and doctoral degrees. A few U.S. schools offer undergraduate or graduate certificates. Foreign terms may include these names and also certificate, diploma and other terms.

The typical length of study also varies by country and credential. For example, a bachelor's degree in some countries involves three years of study compared to four in the United States. Some use the term "bachelor's with honors" to indicate four years of study.

There are companies that evaluate non-U.S. degrees and academic credentials for a fee. They rely on information that most registrars at U.S. universities use. Registrars evaluate student applications for compliance with school entry standards.

2-10 LICENSING AND CERTIFICATION FOR SAFETY PRACTITIONERS

Figure 2-1 gives a summary view of how licensing and certification work. To qualify, applicants typically meet education or training standards, offer experience in the practice domain, and sit for and pass an examination. The process helps employers and the public by assuring that someone has the background and knowledge essential for practice. The process verifies educational credentials and work experience.

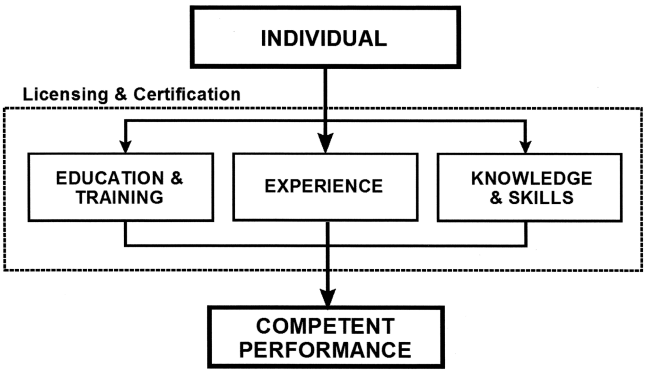


Figure 2-1. Licensing and certification procedures verify education or training, work experience and knowledge and skills.

TABLE 2-4 Major Certifications in Safety and Related Practices

Practice	Certification	Organization
Safety Professionals	Certified Safety Professional (CSP)	Board of Certified Safety Professionals
Industrial Hygiene	Certified Industrial Hygienist (CIH)	American Board of Industrial Hygiene
Health Physics	Certified Health Physicist (CHP)	American Board of Health Physics
Occupational Health	Certified Occupational Health	American Board of Occupational
Nursing	Nurse (COHN and COHN-S)	Health Nurses
Occupational Medicine	Board Certification in Occupational Medicine (BCOH)	American Board for Preventive Medicine

Licensing of Professions

States have a responsibility to protect the health, safety, and welfare of the public. One way states do that is through licensing of professions offering services directly to the public. In each state, doctors, lawyers, barbers, and others must sit for and pass an examination related to their practice. If they qualify for the examination and pass it, they receive a license. The license authorizes them to practice their profession or trade in the awarding state.

Engineers also have state licensing, sometimes called registration. However, fewer than 20% of engineers become licensed. Most civil engineers do, because they work on public buildings and facilities. The license helps protect the public. Most other engineers do not get a license to practice because they work for employers. The employers offer products and services to the public and the liability attaches to the employer, not their employees.

Certification

There is no licensing for many professions. The main reason is that they do not provide services directly to the public. In order to gain recognition and credibility, many professions in the United States have set up certification. Practitioners must qualify and pass one or more examinations related to practice to become certified. The process is almost the same as for licensing. Certification marks a level of professionalism and competency for those who achieve it. Certification does not prevent anyone from practicing.

To assure the public that a certification organization and program follow recognized practices, certification accreditation has been set up. The National Commission for Certifying Agencies (NCCA) is an organization in the United States that accredits certification programs. It sets certification standards covering fairness, quality for examinations and passing scores, continuing competency and other factors. NCCA accreditation is open to any certification. Certification organizations apply for accreditation and NCCA reviews their operations in detail. If an organization and its program are in compliance with the standards, NCCA awards program accreditation for a limited time. Standards require periodic reevaluation to keep accreditation.

Another U.S. certification organization is the Council of Engineering and Scientific Certification Boards (CESB). This organization also sets standards and awards accreditation for individual certifications. The organization limits its participation to engineering, science, and related domains.

An international accreditation process is operated by standards organizations in individual countries. The standard is universal under the leadership of the International Standards Organization (ISO). The standard is ISO/IEC 17024 covering certification of persons. In the United States, the American National Standards Institute (ANSI) handles accreditation under this standard.

A significant number of certifications are available in the safety, health and environmental domains of practice. Table 2-4 lists a few of the important certifications. Refer to the current listing of each accreditation organization to find accredited certifications and their organizations.

EXERCISES

1. Discuss the importance of teamwork to achieve safety performance. Identify who should participate in the team.
2. Contact one or two safety, health, and environment professionals. Find out the following information:
   (a) How they learned about this field.
   (b) How they prepared for practice.
   (c) How they gained their first job in the field.
   (d) Which functions are included in their current position.
   (e) On what functions they spend most of their time.
   (f) How much they earn and what benefits they receive.
   (g) Which aspects of their job give them the most satisfaction.

3. Identify which schools in your state offer degrees at any level in safety and related fields of study.
4. Locate the names of three higher education institutions that at least one state does not recognize. Look for their web sites to see if they still exist and if they offer safety or related degrees.

REVIEW QUESTIONS

1. What are the main responsibilities of each of the following specialists?
   - **(a)** Safety professional
   - **(b)** Safety engineer
   - **(c)** Industrial hygienist
   - **(d)** Fire protection engineer
   - **(e)** Health physicist
   - **(f)** Ergonomist
   - **(g)** Occupational health nurse
   - **(h)** Occupational health physician
   - **(i)** Human Resources manager
2. What are significant differences between licensing and certification? How are they similar?
3. Why do states license only certain professions and trades?
4. Explain how one can find out about the quality of a college or university in the United States. Explain how one can determine the quality of a safety or related degree program.

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1 www.bls.gov/ooh/

2 ANSI/ASSE Z590.2-2003, *Criteria for Establishing the Scope & Functions of the Professional Safety Position*, American Society of Safety Engineers, Des Plaines, IL, 2012.

3 Roger L. Brauer and Steven Schoolcraft, *International Professional Safety Practice: A Comparison with U.S. Practice*, Presentation No. 607, Proceedings, American Society of Safety Engineers Professional Development Conference, June 2008.

4 H. W. Heinrich, "The Need for Specialists in Safety," *Industrial Safety Survey*, XI(4), October–December 1943, Montreal.

5 www.asse.org/professionalaffairs_new/directory/

6 http://ope.ed.gov/accreditation/

7 www.chea.org/search/default.asp

8 www2.ed.gov/students/prep/college/diplomamills/index.html

9 www.chea.org/degreemills/default.htm

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CHAPTER 3

FUNDAMENTAL CONCEPTS AND TERMS

Safety came to the fore around 1900. Since then, those concerned with safety have created definitions of terms and developed theories for accident causation. They offered concepts for dealing with safety and preventing accidents. Some recommendations have withstood the test of time but others did not. Safety practitioners should be aware of these terms, concepts and approaches for safety.

Some find the safety ideas useful. They often help practitioners' thinking. Practitioners need to know the limitations of these terms, concepts and ideas as not all apply universally. Some are inadequate, but still appear in safety discussions and literature and some help in communicating with others working to achieve safety.

3-1 SOME BASIC TERMS

Safety

Any discussion of terms related to pursuing safety begins with the word safety. A common definition is the following:

> *Safety is the state of being relatively free from harm, danger, injury or damage.*

There are two ways to look at the meaning of the word. One approach has an event perspective. People assume that events can occur that lead to injury, illness, and death. When those events do not occur, one is safe or has achieved safety. Some may view this from a probability viewpoint. A person is safe when they beat the odds of adverse events.

Another approach is a reverse look at adverse events. It assumes there were reasons why adverse events did or did not occur. It is a causal perspective and envisions that one can act to prevent adverse events.

Safety Engineering

Safety engineering is an important part of safety:

> *Safety engineering is the application of engineering principles and practices to the recognition, evaluation and control of hazards that can lead to accidents and incidents.*

The definition suggests that one must understand engineering principles. Also one must know how to apply engineering practices as a unique contribution to achieving safety. An important part of this is having the knowledge and skill for engineering design.

Hazard

A basic concept of a hazard is an obstacle or barrier. In safety, a hazard infers a cause or condition that can lead to adverse events. Here is one definition of the word hazard:

> *The potential or inherent characteristics of an activity, condition, or circumstance which can produce adverse or harmful events and consequences.*

Note that the definition identifies a hazard as an attribute of three items: activity, condition, and circumstance. That means that a personal action can be a hazard. It means that a characteristic of a machine, operation, or process can be a hazard. The idea of a circumstance suggests that something surrounding or inherent in an adverse event can be a hazard. The event may be simple or complex.

The definition states that hazards "can" lead to adverse events. Hazards do not always lead to adverse events. There is a probabilistic element in the concept.

The idea of hazards as a part of safety is critical. It suggests that events have causes.

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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Control

In the safety context, a control is any means of reducing the likelihood or severity of an accident or incident.

There are two main classes of controls. The first is engineering controls. They include modifications of equipment, processes, components that eliminate or reduce hazards and the potential for accidents or incidents.

The second is administrative controls. They involve procedures, use of personal protective equipment, training, supervision and similar approaches. They do not remove hazards. They can help reduce the potential for accidents and incidents.

Risk

Safety uses the word risk mainly as a noun. Risk infers possible loss or harm. Safety has the following risk concept:

> *Risk is the chance or likelihood of an adverse event and the potential severity that may result.*

Risk considers an activity, condition or circumstance and estimates the likelihood that it can lead to an accident or incident. Risk also considers which injuries, illness, death and property loss can result, and the severity of an event, should it occur.

The insurance industry uses risk differently. Risk is that which a company insures, such as a person or a property.

Later, details of risk analysis and risk management will make use of the safety definition for risk.

3-2 ACCIDENTS AND INCIDENTS

Accident Defined

The word accident in the English language creates some difficulties. The word can infer different concepts to people. For example, someone tells a friend about an accident. The immediate response of the friend is to ask about injury or damage. The accident may or may not have had adverse effects. That confusion results from the word accident lacking a precise meaning.

The dictionary defines accident as:

> *A happening or event that is not expected, foreseen or intended.*

The word accident often includes several characteristics, none of which may be true.

- To many, the word accident includes consequences, such as injury, loss, or damage. Some accidents have no consequences.
- The word also suggests an immediacy between event and effects. With any accident there may be immediate consequences. Some accidents have delayed consequences.
- We also think of consequences as immediate, not delayed.
- We think of an accident as a chance event.
- We think of an accident as a sudden event.

As a result, there is confusion about the term accident. Many adverse events in safety and health occur over periods of time. In some cases, the consequences take some time to appear. Many adverse events are not chance events. They are predictable. Many accidents represent a sequence of events that evolve slowly.

This leads to an alternative definition for accident:

> *An accident is an unintended, unplanned, single or multiple event sequence that results from hazards and may result in immediate or delayed undesirable effects.*

Incident Defined

Many organizations use the term incident to refer to an unplanned event or event sequence. This resolves some of the problems with the term accident. The word incident focuses on an event. The event may or may not have consequences. Incident does not carry the connotation that the event sequence is a chance event. Incident does not rule out the potential for prevention. An incident does not suggest a rapid event.

The word incident helps solve some of the problems with the word accident. However, because the word accident has such broad and common use, one cannot replace it completely.

This book will use both terms somewhat interchangeably. However, use does not assume that all characteristics for the word accident apply.

3-3 CONSEQUENCES

There are many kinds of consequences when adverse events occur. There may be injuries, illnesses, death, property damage, or harm to the environment. There are other consequences as well. Examples are loss of production or sales. Other consequences often require additional work, such as conducting investigations and completing forms, reports, and records. There may be cleanup, recovery, and reconstruction tasks. There may be emergency and medical treatment of individuals. There may be a need to rebuild brand and public image.

There are some important terms related to consequences. The National Safety Council[1] offers the following definitions.

Injury

Injury is physical harm or damage to the body resulting from an exchange, usually acute, of mechanical, chemical, thermal, or other environmental energy that exceeds the body's tolerance.

Injury Source

An injury source is the principal object such as tool, machine, or equipment involved in an accident and usually the object inflicting injury or property damage. An injury source also has the names *agent* or *agency*.

Occupational Injury

An occupational injury is any injury, such as a cut, fracture, sprain, amputation, or other injury, which results from a work accident or from a single instantaneous exposure in the work environment.

Occupational Illness

An occupational illness is any abnormal condition or disorder other than one resulting from an occupational injury caused by exposure to environmental factors associated with employment. It includes acute and chronic illnesses or diseases that may result from inhalation, absorption, ingestion, or direct contact.

Fatal Accident

A fatal accident is an accident that results in one or more deaths within one year.

Unintended Injury, Illness and Death

For many decades, people called injury, illness, and death statistics resulting from adverse events accident statistics. There were accidental injuries, accidental illnesses, and accidental deaths.

The confusion related to the term accident led to use of the term "unintended." Now the preferred terms are unintended injuries, unintended illnesses and unintended deaths. Also influencing the change in terms were workplace violence cases involving intentional incidents and consequences. Such cases don't fit the idea of accidents.

Relationships Between Accidents/Incidents and Consequences

Let us look at the relationships among accidents with no consequences and those with minor or major consequences. Some assume a no consequence accident may provide valuable information to help prevent those with consequences. To promote this preventive idea, Heinrich[2] conducted a study. He found that among 330 accident cases, there were 300 with no consequences, 29 with minor consequences and 1 with major consequences. The ratio itself is not significant, since others could not reproduce the ratio based on additional studies.[3,4] The importance derives from seeking to create preventive strategies based on experience gained from low- or no-consequence incidents.

3-4 COSTS

As noted in Chapter 1, cost is an important reason for safety. There are several ways to organize costs related to accidents and incidents.

Direct Versus Indirect Costs

One approach divides accident-related costs into direct and indirect costs. Chapter 1 introduced this approach. Some refer to indirect costs as hidden costs. Direct costs are expenses incurred from and directly linked to an accident. Direct costs typically include:

- medical expenses;
- compensation to injured employees for time away from work, such as vacation or sick leave, and long-term disability payments; and
- repair or replacement of damaged equipment, buildings, and other items.

Indirect costs are real expenses associated with accidents. It may be difficult to assess these expenses for individual cases. Table 3-1 lists eleven classes of indirect

TABLE 3-1 Hidden Costs Associated with Incidents

A.	Lost time of injured employee.
B.	Time lost by other employees to help injured co-worker, to see what is going on and to discuss events.
C.	Time lost by a supervisor to help injured worker, investigate incident, prepare reports, and adjust work and staffing.
D.	Time spent by company first aid, medical and safety staff on case.
E.	Damage to tools, equipment, materials or property.
F.	Losses due to late or unfilled orders, loss of bonuses or payment of penalties.
G.	Payments made to injured employee under benefit programs.
H.	Losses resulting from less than full productivity of injured workers upon return to work.
I.	Loss of profit because of lost work time and idle machines.
J.	Losses due to reductions in productivity of co-workers because of concern or reduced morale.
K.	Overhead costs that continue during lost work.

Source: Adapted from H. W. Heinrich, *Industrial Accident Prevention*, 4th ed., McGraw-Hill, New York, 1959.

costs. They help direct attention to the importance of preventing accidents. Some people may want to add other classes to this list or remove them.

Direct costs can be compared to indirect costs. Many claim that indirect costs are somewhat higher or much higher than direct costs. Various authors have defined the ratio between the two categories.[5] Their ratio values differ a lot. The ratios depend on how authors have classified source data and the context of the cases analyzed. Also, the costs in either category change over time. As a result, the ratios are not very useful.

Total Costs

When one can measure both direct and indirect costs in accident cases, it is helpful to consider the total cost of cases. The total costs help convince managers about the importance of preventing accidents. In addition, one can link accident costs to business metrics, such as profit. Accident costs are part of the operating costs of an organization. A company can reduce its operating costs by improving productivity and reducing any operating expenses. This includes reducing accidents and their costs.

Insured Versus Uninsured Costs

Another way to consider the costs related to accidents is by dividing costs into insured and uninsured costs. If an insurance policy covers an accident, most likely it pays the expenses. Insurance may have limits on total claims or on actual elements covered.

Insured costs are those paid by an insurance policy. Uninsured costs are those not paid by an insurance policy. When analyzing accident costs this way, one must also include the premiums for any insurance policy involved.

Dividing accident costs as insured or uninsured can become complicated in some cases. Large companies or organizations may be self-insured. In that case, the company or organization will cover all accident costs.

Incident-Cost Relationships

There is also an important relationship between the frequency of injury accidents and direct costs. A concept termed *the vital few*, originally introduced by Gordon Lembke of Wausau Insurance Companies, recognizes that similar accidents have different costs.

Vilfredo Paretois (often spelled Pareto in the English literature), an Italian economist of the nineteenth century, was the first to apply unequal distributions to economic data. Some call this *Pareto's Law*. He noted that significant items in a given group normally are a relatively small portion of the total. For example, recognize that a small portion of accidents, assume 20%, will account for a large portion of all accident costs. The remaining 80% account for a small part of the total costs.

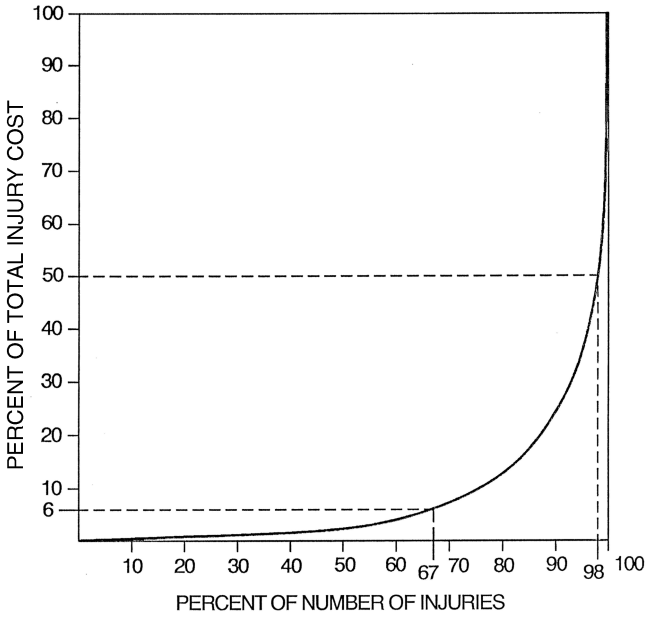


Figure 3-1. The Vital Few concept shows that a few accidents account for the majority of the insured costs. (Reproduced with permission from Wausau Insurance Companies.)

For a group of similar incidents resulting in injuries and direct costs (insurance claims), only a small percentage of the injuries account for most of the total costs of the group. Most of the injuries account for a small portion of the total injury costs. Figure 3-1 illustrates an unequal cost distribution based on many similar incident cases, the Vital Few concept.

3-5 ACCIDENT CAUSES: UNSAFE ACTS, CONDITIONS AND CIRCUMSTANCES

Why do accidents occur? Accidents and incidents have causes. Some would argue there are causes for every accident or incident. Key for safety practitioners is understanding the causes and using that knowledge to prevent future incidents.

The definition of hazard earlier in this chapter lists three elements that can lead to accidents: activities, conditions and circumstances. Causes of accidents often involve unsafe acts (activities) and unsafe conditions. When performing risk analysis, one may also consider circumstances surrounding a potential event. It is not uncommon for the circumstances to add to the severity of the event. For example, an automobile crashing into another vehicle may deflect into a gasoline storage tank located nearby but not directly involved in an incident. The event just happens to occur at the tank's location.

If the tank leaks and catches on fire, the incident becomes a lot more serious.

The role of unsafe acts and unsafe conditions as accident causes has a long history. The relative importance of each is to be determined. Early in the 1900s, there was a strong focus on accident prevention and that included training workers. People assumed that human behavior was a major cause of accidents. Early focus on prevention also emphasized prevention through design to address unsafe conditions.

In the 1930s, Heinrich studied the relative role of unsafe acts and unsafe conditions. He concluded that 88% of cases involved unsafe acts, 10% involved unsafe conditions and 2% had no preventable cause. A different study in the 1960s by the State of Pennsylvania found both unsafe acts and unsafe conditions were causes for nearly every accident studied. The ratio between the two causes is irrelevant. Any ratio does not provide a suitable strategy when analyzing hazards and accident prevention. Preventing accidents must consider both as well as the surrounding circumstances.

3-6 ACCIDENT AND INCIDENT THEORIES

Safety practitioners need to recognize several premises when addressing accident prevention:

- Accidents have causes.
- Accidents often involve hazards that include unsafe acts (activities), unsafe conditions, and other circumstances.
- Accidents may or may not have consequences.
- Consequences may be minor or major (severe).

Understanding these points helps practitioners apply accident theories and models. Accident theories and models provide some insights when investigating accidents or conducting hazard and risk analysis aimed at prevention.

The Domino Theory

Heinrich produced some early thinking about accident prevention. He recognized the importance of unsafe acts and conditions and created a theory called "the Domino Theory" because Heinrich used a row of dominos to illustrate his theory. The theory states that an accident sequence is like a series of five dominos standing on end. One falling can knock the others over. The five dominos in reverse sequence are: (1) an *injury* caused by (2) an *accident*, which, in turn, is caused by (3) *unsafe acts or conditions*. Causes for the latter are (4) *undesirable traits* (such as recklessness, nervousness, violent temper, lack of knowledge, or unsafe practices) resulting from one's (5) *social environment*. Removing or controlling contributing factors will stop the accident sequence. The theory places strong emphasis for accident prevention on the middle domino: unsafe acts and unsafe conditions. While his idea helps with preventive thinking, the Domino Theory includes characteristics of people that we would not emphasize today. It is worth knowing about his theory and its limitations.

Serial and Parallel Theories

Heinrich's Domino Theory is a serial theory. That means that only one class of domino in the sequence can lead to the next domino. In contrast, a parallel accident causation theory will look for combinations of items working together that lead to an accident. For example, suppose a driver had difficulty stopping a car when stepping on the brake pedal. A serial theory might learn that the driver's foot slipped from the pedal. A parallel theory might find the foot slipping from a worn and slippery pedal. It may also find there was some wet substance on the sole of the driver's shoe. In addition, the pedal material and sole material together may have created a low friction interface.

Single Factor Theories

Many people who deal with accident prevention look for a single or major cause for certain accidents. A single factor theory assumes that when one finds a cause, there is nothing more to find out. Very often the cause is the immediate or proximate cause, but that does not consider other elements that can contribute to the event.

Single factor theories have limited value in prevention. Sometimes they are a hindrance to effective prevention. Most often there are other causes beside one immediate cause. Relying on a single factor theory will cause one to overlook other important preventive actions.

Chapter 36 will introduce root cause analysis, which goes well beyond a single factor approach and drills deep into causes.

Multiple Factor Theories

In multiple factor theories, several factors combine in random or some logical fashion and lead to accidents. Factors may include any of the three elements of a hazard: activities, conditions, and circumstances.

Different authors have proposed multiple factor models to help safety practitioners think through accident causation. Grose[6] proposed a model involving four Ms: *man*, *machine*, *media, and management* (see Figure 3-2). Obviously, Man refers to people, Machine includes any kind of

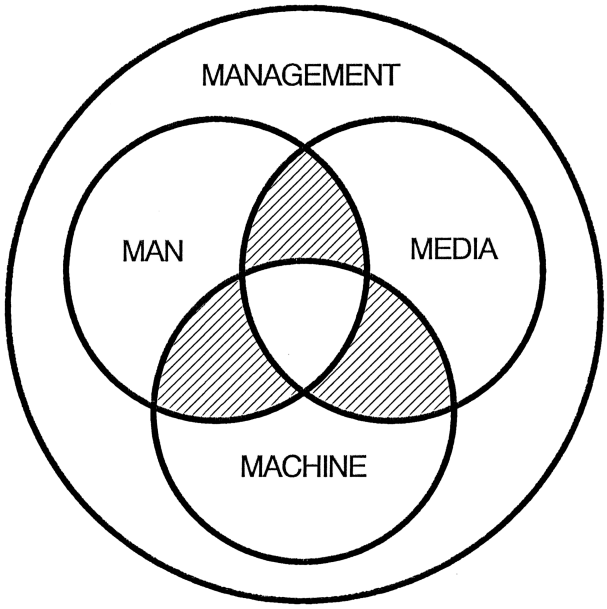


Figure 3-2. Four system safety factors: the Four Ms. (Roland, 1990). Reproduced with permission from John Wiley & Sons, Inc.

equipment or vehicle, Media includes environments, roads, and weather, and Management is the human context in which the other three Ms exist and operate. Roland and Moriarty have a very similar model.[7]

When analyzing hazards, one can think through all of the characteristics falling under each of the four Ms in the model. For example, characteristics of people are age, gender, height, skill level, amount of training, strength, posture, motivation, emotional state, language spoken, and so on. Characteristics of machines might include size, weight, shape, energy source, amount of energy, type of action or motion, availability or placement of controls, materials of construction, or protection systems in place. Characteristics of media might include thermal conditions, rain or snow, roadway width, surface conditions, noise level, etc. Characteristics of management might be management style, organizational structure, communication flow, policies, and operating procedures.

Part V will cover several techniques for working on prevention that apply multiple factor models. Multiple factor models may use quantitative or qualitative analysis. Statistical techniques, such as factor analysis, multiple regression analysis and other multivariate methods may be useful. Fault tree analysis, failure mode and effects analysis and other approaches help identify characteristics that together can lead to undesired events.

Energy Theory

William Haddon worked primarily in the prevention of vehicle accidents. He developed a theory[8] that involves the transfer of energy, "the Energy Theory," as a way to think about prevention. His approach is called "the Energy Release Theory." The Energy Theory suggests that quantities of energy, means of energy transfer and rates of energy transfer relate to the kinds of injuries and severity of injuries. His theory helps resolve many safety engineering problems and offers a way to think about what can happen. Haddon's approach involves a parallel theory of prevention. Multiple actions working concurrently can reduce the likelihood and severity of an accident.

Based on the energy transfer model, Haddon suggests ten strategies for preventing or reducing losses or consequences of accidents. The order for these strategies builds on potential accident sequences:

1. *Prevent the marshaling of energy.* In this strategy the goal is not producing energy or changing it to a form that cannot cause an accident or injury. Examples are not producing gunpowder, substituting a safe substance for a dangerous one, preventing the accumulation of snow where avalanches are possible, removing snow where slips and falls can occur, not letting small children climb to levels above the floor, and not setting a vehicle in motion.
2. *Reducing the amount of energy marshaled.* Examples are keeping vehicle speeds down, reducing the quantities or concentration of high energy or toxic materials, limiting the height for objects, and reducing machine speed to the minimum needed during cleaning or maintenance of an unguarded machine.
3. *Prevent the release of energy.* Examples are using various means or devices to prevent elevators from falling, flammables from igniting, or foundations from being undercut by erosion.
4. *Modify the rate of energy released from its source or modify the spatial distribution of the released energy.* Slowing the burning rate of a substance or using an inhibitor and reducing the slope of roads are examples.
5. *Separate in space or time the energy released from the potentially damaged structure or the potentially injured human.* Examples include separate paths for vehicular and pedestrian traffic, placing electric power lines out of reach, using traffic signals to phase pedestrian and vehicular traffic, and using energy-absorbing materials.
6. *Separate the energy being released from a structure or person who can suffer loss by interposing a barrier.* Safety glasses, barrier guards, radiation filters or shields, median barriers on roadways, thermal insulation, and explosive barricades are examples of barriers.
7. *Modify the surfaces of structures that come into contact with people or other structures.* Rounded corners, blunt

objects, dull edges, and larger surface areas for tool handles are examples.

8. *Strengthen the structure or person susceptible to damage.* Examples of this strategy are fire- and earthquake-resistant construction of buildings, training of personnel, and vaccination for disease.
9. *Detect damage quickly and counter its continuation or extension.* An example of this strategy is sprinklers that detect heat and spray water to prevent the spread of a fire. Another is wear indicators built into the treads of vehicle tires.
10. *During the period following damage and the return to normal conditions, take measures to restore a stable condition.* Examples are rehabilitating an injured worker and repairing a damaged vehicle.

Errors in Management Systems

Some involved with management methods believe that errors people make are management issues, not worker issues. Errors by workers are attributes of poor management processes. This concept is a critical part of management through quality espoused by Juran[9] and Deming.[10] Deming claimed that 85% of errors are due to poor processes. Only 15% of errors involve worker skills. He felt no matter how hard someone tries to improve within a given process, it is not possible unless there is a change in the process itself. He focused on management getting the processes right, reducing errors in poorly operating processes, and avoiding the need to make corrections after errors occur. Incidents and accidents are forms of errors, they interrupt processes and reduce quality. By engaging workers and managers to work together, it is possible to improve processes.

Juran defined critical processes as ones that present serious dangers to human life, health, and the environment or create losses of very large sums of money. Such processes require planning and design to reduce opportunities for human error to a minimum. Emphasis is on continuous improvement to achieve quality. That also emphasizes reducing accidents.

The management concepts of Deming and Juran are often called "Total Quality Management." Their solution to bad processes was constant improvement. Today, the extension of their approach is called "Six Sigma."[11] There are many references to these management approaches in the management literature. They offer safety practitioners ways to use management techniques to reduce accidents and to communicate with managers.

To a great extent this approach is similar to Prevention through Design (PtD). The approach emphasizes making changes through design and redesign. That can include engineering changes and changes to equipment and methods.

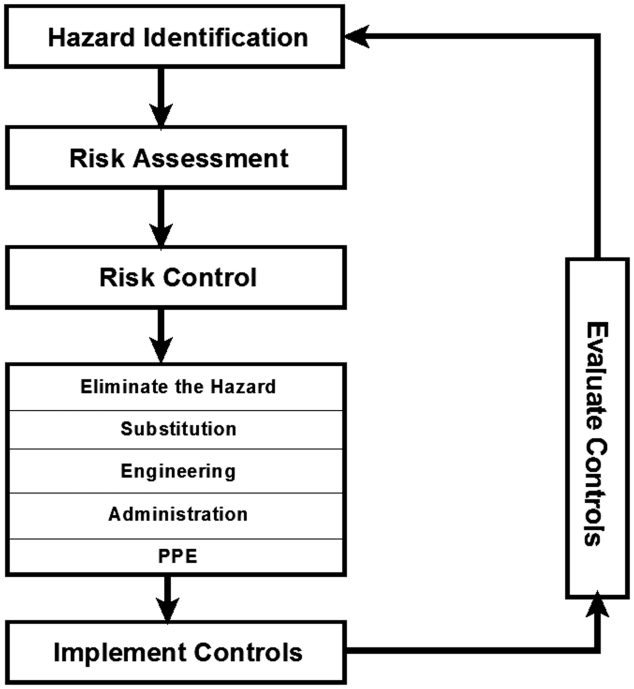


Figure 3-3. A commonly used approach for hazard control and continual safety improvement.

3-7 PREVENTIVE STRATEGIES

Many ways to establish and implement prevention of accidents and their consequences have been suggested and this discussion will review some of these approaches.

Hazard Controls and Risk Reduction

The most universal approach today involves a procedure outlined in Figure 3-3. The first step is hazard identification. When identifying hazards, one can apply the concepts, theories, and models listed earlier in this chapter. This will include a review of activities, conditions, and circumstances involved in hazards. The analysis may include identification and evaluation of potential consequences of undesired events.

The next step involves risk assessment. Here one looks at the frequency or likelihood and severity of events involving the identified hazards. This includes event patterns, such as intermittent or continuous.

The third step is identifying, analyzing, and implementing risk controls. Important here are the priorities for controls, listed in Table 3-2. This list is called "the Hierarchy of Controls."

Step four is reviewing and evaluating control measures put into place. The goal is to ensure that measures are working and are effective.

TABLE 3-2 Priorities for Hazard Controls: the Hierarchy of Controls

- Eliminate hazards by changing processes so the hazards do not exist.
- Reduce the hazard level through substitutions, process changes and redesigns.
- Provide safety devices, such as enclosing a hazard or applying other engineering controls.
- Provide warnings, which may be visual or auditory.
- Provide administrative controls that include:
  - safety procedures and job changes.
  - safety training.
  - use of personal protective equipment.

Concept-Driven Strategies

One can use accident theories and accident sequence models presented earlier in this chapter to help formulate accident prevention strategies. For example, one can apply Haddon's energy theory to prevent accidents and reduce their consequences or one can apply the 4 Ms model to help think through the elements that may lead to accidents in particular situations.

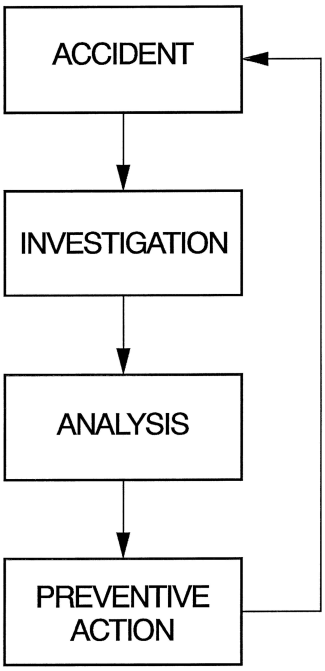


Figure 3-5. A reactive approach for deriving preventive actions from accidents.

The Three Es of Safety Another concept for accident prevention builds on the *Three Es of Safety*. The three Es are *engineering*, *education*, and *enforcement*. This approach links to the idea presented earlier that unsafe acts and unsafe conditions result in accidents. Figure 3-4 shows how the three Es links to that idea. Engineering primarily seeks to prevent unsafe conditions. Engineering can also deal with unsafe acts. Later chapters will cover ergonomics and human behavior as part of safety engineering.

Education primarily addresses unsafe acts. However, there are many training needs in safety that go beyond unsafe acts themselves. Engineers need to know how to recognize and control hazards in their designs. Workers and supervisors need to know how to recognize hazards on the job. They need to know which controls can help prevent accidents. Everyone needs to know which prevention strategies, policies and methods are in place.

Enforcement applies to all aspects of accident prevention. It ensures implementing and complying with laws, regulation, standards, and policies.

A fourth E, *enthusiasm*, is sometimes added to the first three Es. It refers to motivating people to follow safe practices and contribute effectively to safety.

Case-Driven Strategies: A Reactive Approach

A reactive approach can be used to develop strategies for preventing accidents. Figure 3-5 illustrates how that

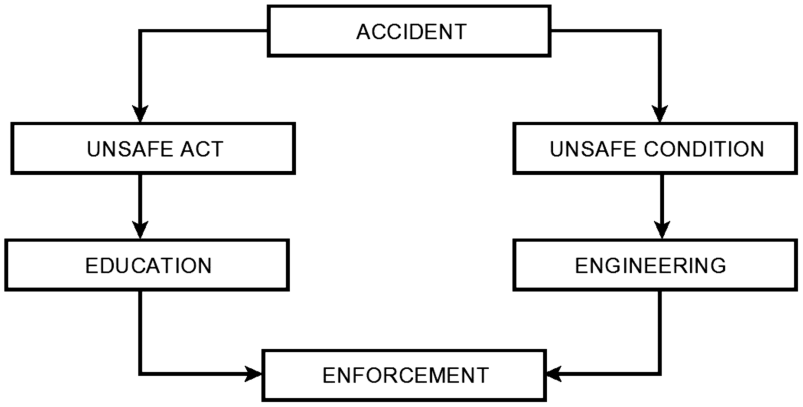


Figure 3-4. A traditional approach for safety improvement that applies the Three Es of Safety.

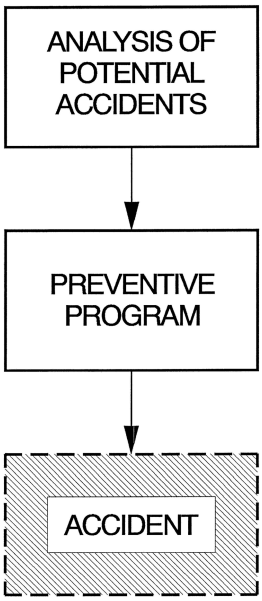


Figure 3-6. A proactive approach for developing preventive actions before accidents occur.

approach works. It starts with accidents. Investigations compile information. Analysis of the information then finds ways to prevent future accidents.

While there is something to learn from every accident, this approach has limited value. The reason is the method starts with accidents. The aim is to prevent them in the first place. Accident investigation data has a use, but it is not the best way to start preventing accidents.

Comprehensive Strategies: A Proactive Approach

An alternate approach is a proactive one. As shown in Figure 3-6, the preventive strategy starts with analysis. The aim is to identify all of the factors that can lead to accidents and the combinations of those factors. Preventive strategies come from the analysis. The approach seeks to avoid having accidents at all. Several detailed strategies build on this approach.

Focus on High Frequency Cases Frequency strategies try to prevent as many accidents as possible. The aim is to reduce accidents that occur often as a way to lower accident rates. In some cases this may be an effective approach. For example, it is known that nearly half of work-related injuries occur during the first year on the job. Half of those cases occur during the first three months of employment in a new position. A good strategy is to teach people in new roles a lot about what can go wrong and how to prevent adverse events. This is a frequency-based strategy.

Focus on High Severity Cases Severity strategies focus on potential accidents that lead to major injuries, long-term disability, serious illnesses, death, impact many people or cause major property damage. Data from national injury statistics by industry, occupation, type of work or other factors help pinpoint risks.

High Cost Another approach to prevention strategies looks at accident costs. A study of accident cases and insurance claims that applies principles such as the Vital Few (see Figure 3-1) can help focus on high cost events. Often high cost cases are high severity cases.

Combinations Perhaps the best approach to accident prevention strategies involves a combination of approaches. Safety practice today requires the use of all approaches. Preventive strategies must use all the available tools to think about what can go wrong and how to prevent adverse events. The aim is to prevent accidents from happening at all. An effective strategy requires applying a broad range of knowledge. Examples are:

- past cases;
- cases reported by others;
- internal and national statistics;
- knowledge of hazards and controls;
- techniques for effectively motivating and working with people;
- an understanding of business goals and performance.

Safety Management Systems

Once again safety management systems become important. This approach integrates many of the other approaches. Part V will provide more details. Figure 3-3 offered one view of the process for accident prevention through safety management systems. The process involves employer representatives, employees, and a safety planning facilitator, often a safety practitioner. Each type of participant brings different viewpoints and experience to the process.

The initial task is hazard identification. Participants apply information from the theories, models, and definitions above, along with other knowledge and experience. The next task is to conduct risk assessments on the identified hazards. Based on results, the participants select acceptable levels of risk and appropriate hazard controls. Each possibility needs evaluation to determine the potential for risk reduction. The evaluation will apply the priorities for controls listed in Table 3-2. Then they test and implement one or more selected controls. The final task is to evaluate the effectiveness of implemented controls. The panel may apply the evaluation results in working through the process again.



Figure 3-7. Many things are not clearly safe or unsafe. Some things fall in a region of uncertainty.

3-8 HOW SAFE IS SAFE ENOUGH?

A difficult issue is deciding what level of safety is sufficient. It is not possible, or economically possible, to remove all risks for work, travel, recreation, and other activities. Society may set standards on what is acceptable. Individuals may hold personal standards for acceptable risk. Different individuals will not fully agree on standards. Employers may determine what is acceptable for their workplaces and expect people to meet those standards. Standards may vary over time and not be constant. Who pays for protection will also affect the standards of risk.

Figure 3-7 illustrates the issue. There is a region in which all will agree on what is safe. There are conditions, behaviors, and circumstances that all will agree are not safe. Between those two zones is a region of uncertainty. Someone must decide how far to move the boundary of acceptable risk.

Often engineers have a dilemma as they must decide what is acceptably safe. This may occur in design or in other engineering roles. In order to make good decisions, engineers must apply an array of preventive strategies outlined above. Essential tools are hazard recognition, evaluation and control. Engineers should engage others to help in the process of deciding how safe is safe enough.

EXERCISES

Obtain copies of completed incident reports. Use data found in each to complete the first four exercises.

1. Identify unsafe acts, unsafe conditions and contributing circumstances in each report.
2. Identify preventive actions that were possible for the cases. Identify any accident theories or models that helped identify preventive actions.
3. Identify possible factors involved in each case using a multiple factor theory, such as the four Ms.
4. Select one or two of the cases and list the hazards potentially involved in each. Suggest which hazard controls might have prevented each case or reduced its severity.
5. Use the history of automobile safety (or some other product) to show the shift in public acceptance of and preference for safety features.
6. Review the management principles of Juran and Deming and identify how safety can be part of continuous improvement and quality.

REVIEW QUESTIONS

1. Give a definition of the word safety.
2. Give a definition of the word accident.
3. What are the deficiencies of the term accident? What term is an alternative for accident?
4. Why is the term incident preferred by some people?
5. Define:
   - **(a)** safety engineering
   - **(b)** hazard
   - **(c)** control
   - **(d)** risk
6. Distinguish between hazard and risk.
7. What are the differences between the following pairs of terms?:
   - **(a)** accidents and injuries
   - **(b)** injuries and illnesses
   - **(c)** accidental injury and unintended injury
   - **(d)** direct and indirect costs of accidents
   - **(e)** insured and uninsured accident costs
   - **(f)** unsafe acts and unsafe conditions
8. Heinrich developed concepts for safety that are still used today. Explain the following and identify their limitations:
   - **(a)** the Domino Theory
   - **(b)** the ratio among no consequence, minor injury and major injury accidents
   - **(c)** the ratio between unsafe acts and unsafe conditions.
9. What is the Vital Few concept? From which economic theory does it derive?
10. What is a single factor theory? What is its main limitation?
11. What are multiple factor theories? How are they helpful in incident prevention?
12. What is the energy theory? Identify at least five strategies for incident prevention based on the energy theory.
13. How are the management theories of Juran and Deming helpful in developing strategies for safety?
14. Explain the four Ms.
15. What are the three Es of safety? What is the fourth E?
16. Explain the steps used to prevent accidents when applying a safety management system.

17. What is a reactive approach to safety?

18. What is a proactive approach to safety?

19. List the priorities for hazard controls.

20. Can one achieve absolute safety? Why or why not?

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PART II

LEGAL ASPECTS OF SAFETY

THIS PORTION of the book discusses a range of legal matters related to safety and safety engineering. Discussions include government laws, regulations, and standards and how they are promulgated. This section covers U.S. federal agencies involved in safety. It addresses private standards and standard setting organizations that affect safety engineering. Workers' compensation and how it is applied in practice are discussed. Chapter 7 reviews products liability that impacts safety engineering, particularly design. The legal theories that impact design are summarized. Chapter 8 reviews an array of record keeping and reporting requirements and procedures for computing some accident and injury statistics.

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CHAPTER 4

FEDERAL LAWS, REGULATIONS, STANDARDS, AND AGENCIES

4-1 INTRODUCTION

As noted in Chapter 1, one of the three main reasons for safety is "it's the law." This chapter will explore how the federal government in the United States structures laws. It will explain how regulations and standards implement the laws. States use similar procedures and may have laws, regulations and standards that complement or conflict with federal law. Also, state and local laws may fill gaps not covered by federal laws.

The federal government is huge, with several million employees. There are many different departments and agencies that administer and enforce federal laws. It also includes research agencies that expand knowledge needed by both the government agencies and its citizens.

For employers, tracking applicable laws and implementing regulations and standards can be difficult. Consider a national construction company. There may be federal, state, and local laws, regulations, and standards that apply to a project in one location. In another location, different laws may apply.

This chapter provides an overview of the federal laws and regulations. Discussion will help safety practitioners understand the promulgation process (passing and implementing laws). Brief summaries will help readers become familiar with many of the key agencies.

4-2 FEDERAL LAWS AND REGULATIONS

The Congress of the United States enacts laws and appropriates money. Members of both the House of Representatives and the Senate propose bills and act on them. When approved by Congress and signed by the president, the bills become the law of the land. Many of the laws intend to protect the public and provide for their health and safety.

To implement and enforce the laws, Congress assigns responsibility for particular acts to organizations within the executive branch or to independent agencies. Most organizations in the executive branch are part of a department, headed by a Cabinet-level Secretary. These organizations may issue regulations and standards that explain how they will implement and enforce the acts. Regulations and standards created in support of an act have the authority of law.

Usually, Acts of Congress do not apply to government agencies. To make laws and regulations apply to executive branch organizations, the president signs executive orders requiring compliance. To make them apply to Congress, an Act must include provisions which include Congress within the scope of the law. Also, Congress may pass a separate Act assigning responsibility to its members and agencies.

Interpretation of federal laws and regulations is not done with absolute authority by an implementing and enforcing agency. The system of justice in the United States gives individuals and organizations the right to *due process*. Citizens and organizations may protest laws and regulations that adversely affect them by having an attorney file a complaint in a federal court. Then, the attorney must argue for the client's position. Also, a citizen or organization can appeal citations for violation of regulations.

Civil and Criminal Law

There are two kinds of laws in the United States: civil law and criminal law. Civil laws deal with the private rights of individuals. Under civil laws an individual (a person or organization) seeks to get compensation for a loss or to prevent a loss from occurring. Criminal laws deal with harmful acts or crimes against individuals, society, or the government. Prosecution of crimes occurs at the state or the federal government, depending on the laws violated. Upon conviction, individuals face fines and imprisonment.

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Violations of safety and health laws and regulations most often involve civil law. Some may involve criminal actions and penalties.

Federal Documents

Proposed and enacted federal laws and regulations appear in certain government publications. This section reviews major publications.

United States Code The *United States Code* is a consolidation and codification by subject of the general and permanent laws of the United States. *Titles* are the main subjects that organize the collection (Table 4-1). The Office of the Law Revision Counsel of the United States House of Representatives maintains the U.S. Code.[1] The published version contains the full text of congressional acts. Periodic updates cover additions, changes and deletions resulting from each session of Congress. Federal laws and data about them appear in a multi-volume, annual publication called *U.S. Statutes at Large*.

There are several methods for labeling congressional acts. Each public law passed has a number. Assume a law is Public Law 91-596. In this example the Act is the 596th law enacted by the 91st Congress. Each Congress sits for two years.

An act may also have a name as part of the provisions of the act. An example is the Occupational Safety and Health Act of 1970. Some acts also have the names of the two individuals who sponsored them as a bill or draft law in Congress. There is one person from each legislative body: the House of Representatives and the Senate. For example, the OSH Act of 1970 is also called the Williams-Steiger Act.

Note that two acts are needed to set a government organization into action: an authorization act and an appropriation act. An authorization act assigns responsibility to a government agency, empowering it to perform certain functions. An appropriation act provides the money for a fixed period to pay for the activities. A federal agency cannot function unless Congress passes both acts. By limiting appropriations, Congress can control the effectiveness of a government agency.

TABLE 4-1 Select Titles Containing Safety and Health Laws, Regulations, and Standards

Title	Subject	Significant contents
21	Food and Drug	Food and Drug Administration
23	Highways	Federal Highway Administration
29	Labor	Occupational Health and Safety Administration
30	Mineral Lands and Mining	Mine Safety and Health Administration
40	Public Buildings, Properties and Works	Environmental Protection Agency
49	Transportation	National Highway Traffic Safety Federal Railroad Administration Other Department of Transportation Agencies

Note: Titles apply to both the U.S. Code and the Code of Federal Regulations.

Code of Federal Regulations Often the provisions of an act itself have little direct impact on engineers and others who must follow them. More often one must comply with regulations issued by an agency in response to an act.

Federal agencies propose and adopt regulations and standards to implement responsibilities assigned by laws. The *Code of Federal Regulations*[2] (CFR) contains adopted final rules. There are annual updates to the CFRs, with certain portions appearing each quarter.

There is an alphanumeric index and naming system that helps locate regulations. The initial number is the title number. This is the same subject index number used for the U.S. Code.

Consider an example from the regulations of the Occupational Health and Safety Administration (OSHA).[3] One part of OSHA's regulations has the identifier 29CFR1910. 29 CFR refers to Title 29 of the Code of Federal Regulations. 1910 refers to that part within Title 29 dealing with general industry.

Within each part are subparts or sections, paragraphs, and subparagraphs. There are 26 subparts, A through Z, in Part 1910. Suppose a full citation for a specific paragraph has the following citation: 29CFR1910.1049(d)(6)(iii)(e). One can locate the specific paragraph for this citation.

Some portions may have a descriptive name. For example, 29CRF1910.146 also has the name OSHA Permit-Required Confined Spaces Standard.

Federal Register Proposed and final regulations, together with supporting data and arguments, appear in the *Federal Register*. The *Federal Register* is a daily publication for communicating regulations and other legal documents of federal agencies to the public. It typically runs 50,000–80,000 pages a year. In presenting proposed or final changes in regulations, agencies may include related information. Examples are supporting data, summaries of research, hearing dates, procedures for submitting comments, arguments for and against the regulation, projected impacts for the private sector, cost-benefit analysis, and effective implementation dates.

Each agency adopts new federal regulations or changes current federal regulations through an orderly process. After publication of proposed additions or changes in the *Federal Register*, there is a period in which interested parties submit comments in writing or at public hearings. Then an agency may modify a proposed regulation, leave it as proposed originally, or withdraw it. Following public comment, a

proposed regulation becomes an official government policy and procedure after publication as a final regulation.

The date of publication forms the basis for citing items published in the *Federal Register*. A table of contents at the front of each daily issue identifies the sections included, the pages on which they appear and the issuing agency.

Other Federal Publications In addition to developing regulations, most government agencies prepare publications for the public or make them available to the public. Many of these help them meet federal regulations. Others may be research, statistical or other kinds of reports prepared by an agency or its contractors. There is an index and listing of all publications prepared for public distribution. It was formerly called the *Monthly Catalog of U.S. Government Publications* from the Government Printing Office. The print version ended in 2004. The electronic replacement is the *Catalog of U.S. Government Publications*[4] that is expanding to include all publications since 1895.

The National Technical Information Service (NTIS) in Springfield, VA, indexes and catalogs research and other reports. Many agencies publish a listing or catalog of their own documents on the agencies' web sites. The Superintendent of Documents prints and sells many government publications.

Several private organizations distribute searchable versions of government regulations and standards and regularly update them as part of the service. Various government and private Internet services provide access to the *Congressional Quarterly*, the *Federal Register*, and proposed federal legislation.

Private Publications Keeping track of changes in federal laws and regulations is a time-consuming task. Some private publishing companies offer current-awareness publications and copies of select regulations. These publishers monitor what is going on in the federal government for various special fields of interest and summarize the actions of federal agencies. The publications often contain copies of proposed and final changes in federal and state laws and regulations. These publications organize information to help readers.

These are some current-awareness publications for many safety topics. They include occupational safety and health, products liability, environment, consumer products, food and drugs, workers' compensation, nuclear energy, mine safety and health, chemicals, hazardous materials transportation, noise, insurance and loss control, and other topics important in safety and safety engineering.

Examples are two private publishers targeting products for safety and health. One company that provides legal monitoring products is Bloomberg BNA.[5] BNA used to be called the Bureau of National Affairs (BNA). Another company is J. J. Keller.[6] It offers a wide range of safety and health publications, including legal monitoring ones. Other publishers offer similar services.

4-3 FEDERAL AGENCIES

There is an online directory of federal agencies.[7] Federal agencies fall within four groups. A few are agencies of the legislative branch of government and a few are under the judicial branch. The vast majority fall under the executive branch. Some are independent agencies.

4-4 LEGISLATIVE BRANCH

The legislative branch enacts the laws. In addition, there are two agencies under Congressional control that are of interest to the safety and health field. These are the Government Printing Office and the General Accounting Office. The Government Printing Office (GPO) is the printing service for the federal government. Copies of most government publications, including safety and health topics, are available through the Superintendent of Documents at GPO. Among other duties, the General Accounting Office (GAO) audits federal agencies. It audits safety and health agencies to determine if they are using their assigned powers properly and are performing their duties well. GAO reviews the regulations of each agency to be sure they reflect the intent of Congress as written into public law. Congress may propose changes to laws based on GAO audits.

4-5 JUDICIAL BRANCH

Complaints and appeals about safety and health laws and regulations of the federal government come under the authority of the Supreme Court. Initially, district courts within each of the 10 judicial circuits of the United States hear cases. Appeals move to circuit courts of appeal and possibly can reach the Supreme Court.

Special organizations hear complaints about enforcement of particular federal regulations. Upon appeal, some complaints may proceed to district or circuit courts. The Occupational Safety and Health Review Commission hears employer appeals of OSHA citations. The Mine Safety and Health Review Commission has a similar function.

4-6 EXECUTIVE BRANCH

The president heads the executive branch of the federal government. Special offices and commissions and 14 departments (this number may change from time to time), headed by Secretaries, report directly to the president. There are also

some standing and specially appointed offices, councils, and commissions that report to the president. Many agencies have offices in each of the 10 federal regions, in states or at more local levels.

One famous example of a special commission was the Kemeny Commission that investigated the Three Mile Island nuclear accident in 1979. Another is the Rogers Commission that investigated the *Challenger* Space Shuttle accident in 1986.

Figure 4-1 presents the key safety and health organizations within the executive branch. Summaries of the primary functions of these organizations appear below.

No list of agencies or their functions is fully up to date. Names and functions often change. Online resources will identify current organizations and functions.

Department of Agriculture (USDA)

Animal and Plant Health Inspection Service This organization is responsible for protecting and improving animal and plant health for the benefit of humans and the environment. Also, it works to control and eradicate pests and diseases and ensure that drugs for animal use are pure and safe.

Food Safety and Quality Service This organization ensures that foods for human consumption are safe, wholesome, nutritious, and of good quality. It sets standards for and inspects meat, poultry, eggs, dairy products, and fresh and processed fruit and vegetables. At times, the inspection methods change to respond to public concern and make better use of knowledge and technology.

Department of Commerce

National Institute of Standards and Technology (NIST) This agency was formerly the National Bureau of Standards. As part of its broad mission, NIST conducts research and develops codes and standards. One area deals with building and fire research, another with public safety. Fire research addresses fire protection and prevention, fire equipment, fire behavior, and safety of consumer and building products. Public safety deals with first responders, tornados, and other emergencies. NIST also undertakes research on nanotechnology.

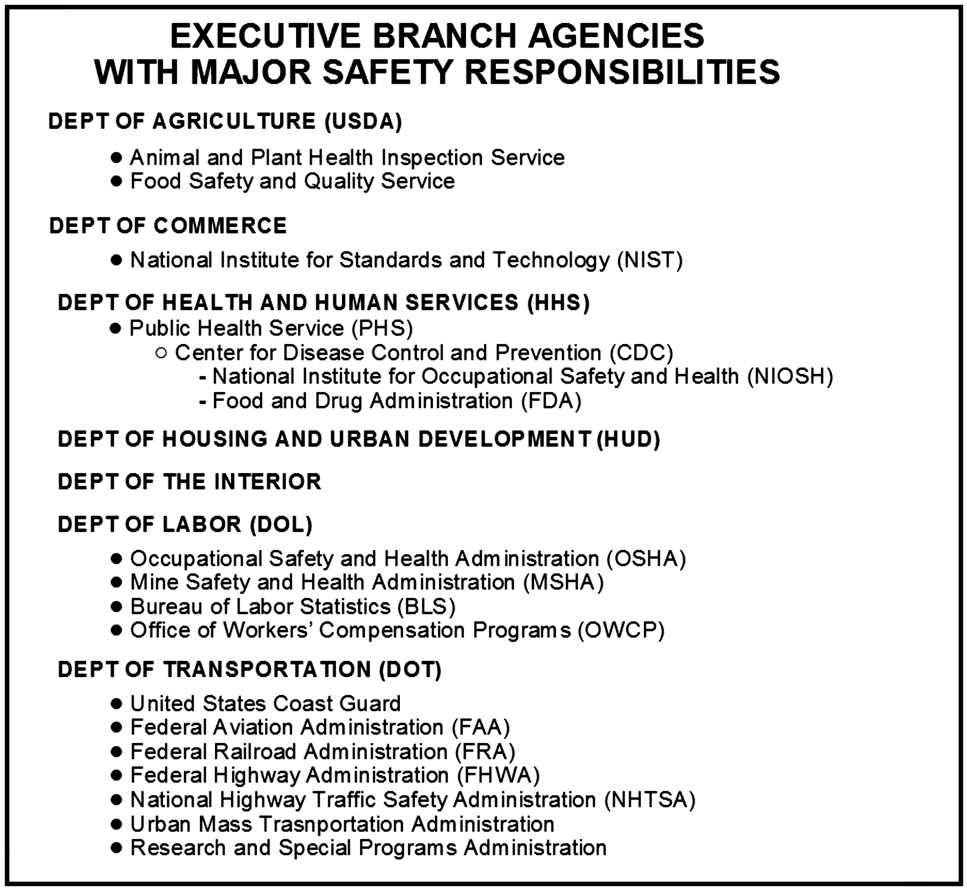


Figure 4-1. Organizational structure for agencies within the executive branch that have major safety responsibilities.

CASE 4-1

For centuries, farmers have bred crops for certain desirable traits. The process offers improved taste and yields, enhanced nutritional value, longer shelf life, and resistance to disease, drought, frost, or insect pests. These changes rely on the natural reproductive processes of the plants. Genetically modified organisms (GMOs) involve the addition of foreign genes that would not occur in nature. The process achieves the desired traits in one generation, rather than several.

The United States base regulation of genetically modified crops on the product. The European Union and some other countries base their regulations on the process. Regardless, there are concerns over food safety risks for consumers and ecology.

In the United States, the GMO issue is complex because no single agency oversees this technology. Regulation of genetically modified crops falls to several federal agencies. The Food and Drug Administration handles regulating the safety of GM crops that humans or animals eat. The Environmental Protection Agency regulates biopesticides and crops genetically engineered to carry toxins that target certain insects. The United States Department of Agriculture also has some responsibilities.

Department of Defense (DOD)

This large agency has several million military and civilian employees. The agency has a safety office that addresses safety of peacetime, training, and combat military affairs. There are also safety organizations and safety schools within each of the services (Army, Navy, Air Force, and the Marines). These organizations deal with the safety of military and civilian personnel. They also address special hazards associated with the manufacture, distribution, use, and disposal of weapons and weapon materials. They oversee the safety of construction and maintenance of military facilities and installations.

Department of Health and Human Services (HHS)

Public Health Service (PHS) The PHS is responsible for promoting and ensuring the highest level of health for Americans. The operating agencies within the PHS have direct and indirect significance for safety and health professionals. Key agencies are the *Centers for Disease Control and Prevention* (which also operates the National Institute for Occupational Safety and Health) and the *Food and Drug Administration*. Programs in the *Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA)* and the *National Institutes of Health (NIH)*, particularly the *National Institute of Environmental Health Sciences* and the *National Library of Medicine*, may provide help for safety and health professionals.

Centers for Disease Control and Prevention (CDC) Within the Centers for Disease Control and Prevention, the most important safety organization is the *National Institute for Occupational Safety and Health (NIOSH)*. The mission of NIOSH is to assure safe and healthy working conditions for all working people. It develops occupational safety and health guidance and suggested standards, conducts research and performs related activities in occupational safety and health. NIOSH is not a regulatory or enforcement agency.

Food and Drug Administration (FDA) The FDA protects people against impure and unsafe foods, drugs, and cosmetics, and against other potential hazards. The *Bureau of Biologics* regulates biological products. The *Bureau of Drugs* regulates drugs, including drug safety, effectiveness, and labeling. The *Bureau of Foods* is responsible for the composition, quality, nutrition and safety of foods, food additives, colors, and cosmetics. The *Bureau of Radiological Health* carries out programs concerned with hazards of and human exposure to ionizing and non-ionizing radiation. The *Bureau of Medical Devices* has responsibility for the safety, efficacy, and labeling of medical devices. Study of the toxic effects of chemical substances is the responsibility of the National Center for Toxicological Research.

Department of Homeland Security (DHS)

This department consolidated several government agencies. While the emphasis is on the security of the nation, some agencies have safety roles.

United States Coast Guard The Coast Guard directs many of its functions to cover safety and health. It conducts search and rescue operations to protect life and property at sea and to remove navigational hazards. It enforces safety standards for the design, construction, equipping, and maintenance of commercial vessels and offshore structures. It investigates marine accidents, is responsible for protecting the marine environment from pollution, and enforces regulations governing the safety and security of ports and the anchorage and movement of vessels in U.S. waters. The Coast Guard operates and maintains a system of aids to navigation. It develops and directs national boating safety programs for small craft, and creates uniform safety

standards for recreational boats and equipment. The Marine Safety Council reviews proposed Coast Guard regulations.

Federal Emergency Management Agency (FEMA) FEMA is responsible for preparedness, mitigation, relief, and response activities for natural, artificial, and nuclear emergencies. FEMA supports training, education, and research for many kinds of emergencies, develops emergency plans and policies, and provides response and recovery help to state and local governments or other organizations when disasters occur. FEMA's United States Fire Administration (USFA) works to reduce the national fire loss through training at the U.S. Fire Academy.

Department of Housing and Urban Development (HUD)

Some of the programs operated by HUD aim to prevent conditions detrimental to health, safety, and welfare in housing and community development. HUD develops standards, including structural, building, and sewer codes, for conventional and manufactured homes.

Department of the Interior

The Department of the Interior protects and preserves public natural resources. This includes activities concerning water quality. The *Bureau of Mines* is a research and fact-finding agency. Areas of research include mine safety, miners' health, and pollution abatement. The department also operates the *National Mine Health and Safety Academy*, which trains inspectors, managers, and other specialists for various safety and health positions in the mining industry.

Department of Labor (DOL)

The Department of Labor has many activities to foster and promote the safety and health of workers. The *Women's Bureau* seeks to improve women's working conditions. Other important agencies are the *Occupational Safety and Health Administration*, the *Mine Safety and Health Administration*, the *Bureau of Labor Statistics* and the *Office of Workers' Compensation Program.*

Occupational Safety and Health Administration (OSHA) OSHA develops and implements standards and regulations, conducts inspections and investigations to assure compliance, issues citations and proposes penalties for violations. It also provides help to employers in meeting standards and regulations through consultations, training programs, and publications.

Mine Safety and Health Administration (MSHA) MSHA is responsible for safety and health in surface and underground mines in the United States. It develops, promulgates, and enforces standards, investigates accidents, and conducts training.

Bureau of Labor Statistics (BLS) This agency conducts economic and statistical research. As part of its activities, it collects injury and illness data from employers and compiles national and regional statistics on worker safety and health.

Office of Workers' Compensation Programs (OWCP) This agency develops and recommends standards for state workers' compensation laws and provides technical help to states. It also administers three workers' compensation programs:

1. federal employees workers' compensation;
2. workers' compensation for longshoremen and harbor workers;
3. the "black lung" benefit program for coal miners and their survivors.

Department of Transportation (DOT)

DOT, divided into eight administrations, conducts programs concerned with all forms of transportation. Responsibilities include the safety of air, water, highway, rail, and pipeline transportation.

Federal Aviation Administration (FAA) As part of its functions, FAA fosters aviation safety through several activities. It issues and enforces regulations and standards for the manufacture, use, and maintenance of aircraft. It certifies pilots, other flight personnel and airports, operates and maintains air navigation systems, manages air traffic, and conducts research in systems, procedures, facilities, and devices to ensure aviation safety.

Federal Railroad Administration (FRA) One of the responsibilities of FRA is administering and enforcing rail safety laws and regulations. The regulations cover locomotives, signals, safety appliances, brakes, hours of service, transportation of hazardous material, and the reporting and investigation of railroad accidents.

Federal Highway Administration (FHWA) In carrying out highway transportation programs, one of FHWA's duties is to make highways safe. FHWA develops and implements standards for highway design, construction and maintenance, promotes the correction of street and highway hazards for vehicles and pedestrians and conducts research in highway safety and traffic. It enforces safety regulations for motor carriers (trucking), seeks noise abatement, and performs activities on the transport of hazardous materials on highways.

National Highway Traffic Safety Administration (NHTSA) NHTSA conducts programs to reduce the frequency of motor vehicle crashes, the severity of injuries, and

CASE 4-2

Each year OSHA publishes performance data identifying compliance issues for employers. Below are samples of this data for 2013.

Ten Most Cited OSHA Standards for 2013

Standard	Total Violations
1926.501 Fall Protection	8739
1910.1200 Hazard Communications	6556
1926.451 Scaffolding	5724
1910.134 Respiratory Protection	4153
1910.305 Electrical – Wiring Methods	3709
1910.178 Powered Industrial Trucks	3544
1926.1053 Ladders	3524
1910.147 Lockout/Tagout	3505
1910.303 Electrical – General Requirements	2932
1901.212 Machine Guarding	2852

10 Most Cited Willful Violations for 2013

Standard	Total Violations
1926.501 Fall Protection	73
1926.652 Excavations	34
1926.62 Lead	25
1910.212 Machine Guarding	23
1910.147 Lockout/Tagout	20
1926.451 Scaffolding	19
1910.23 Guarding Floor & Wall Openings and Holes	18
1910.134 Respiratory Protection	17
1919.119 Process Safety Management	14
1910.178 Powered Industrial Trucks	10

the economic losses that result. It issues Federal Motor Vehicle Safety Standards (FMVSS) that regulate safety features of motor vehicles. It tests vehicles for damage susceptibility, crashworthiness, and ease of repair, and it tests motor vehicles and equipment for compliance with standards. It conducts research and development projects to improve the safety of motor vehicles and related equipment and to make motor vehicles safe for operators, occupants, and pedestrians. It also operates programs to help state and local motor vehicle safety programs and to set motor vehicle fuel economy standards and measure the fuel efficiency of vehicles.

Urban Mass Transportation Administration This agency promotes and tries to improve urban mass transportation, including safety of mass transit equipment.

Research and Special Programs Administration In this branch of DOT, the *Materials Transportation Bureau (MTB)* develops standards, monitors compliance, conducts research, and coordinates the activities of other agencies for transportation of hazardous materials by air, water, rail, highway, and pipeline. In the Transportation Program Bureau, the *Transportation Safety Institute* promotes safety and security management through training programs for government and industry.

4-7 INDEPENDENT AGENCIES

Independent agencies operate under their own administration, not falling directly under any of the three main branches of the federal government. One reason these agencies are independent is to reduce the influence by related agencies that promote a technology or by general policies of a current presidential administration. Presidents can influence the policies and regulations of independent agencies through appointments of administrators.

Consumer Products Safety Commission (CPSC)

CPSC protects the public against unreasonable risk of injury from consumer products. It helps consumers in evaluating the safety of products, develops standards for consumer product safety, and supports research in the causes and prevention of injury, illness, and death from consumer products. It also operates the *National Injury Information Clearinghouse*, which compiles data on consumer product injuries from a sampling of hospital emergency room cases across the country.

Environmental Protection Agency (EPA)

EPA is responsible for protecting and enhancing the environment. It develops and enforces standards, helps state and local governments, and conducts research in prevention and control of air and water pollution. Its responsibility governs pollution from solid waste, noise, radiation, and toxic substances.

National Transportation Safety Board (NTSB)

NTSB helps ensure that all forms of transportation operate safely. It investigates transportation accidents (all civil aviation and serious rail, pipeline, marine, selected highway and other catastrophic accidents) and develops recommendations for other government agencies and transportation industries.

The recommendations cover transportation safety, transport of hazardous materials, accident investigation methods, regulations, and reporting of accidents.

Chemical Safety Board (CSB)

The principal role of the U.S. Chemical Safety Board is investigating accidents to identify the conditions and circumstances that led to the events. It also investigates hazardous conditions that could lead to accidents. The agency uses root cause analysis and other methods to identify causes to prevent events. It makes recommendations to government agencies, companies, trade associations, labor unions, and other groups. It publishes reports and offers DVDs about cases it investigates.

Nuclear Regulatory Commission (NRC)

NRC protects the public health and safety and the environment by licensing and regulating the use of nuclear energy. It also develops and enforces regulations concerning nuclear safety and it inspects licensed activities, sponsors research, and publishes reports related to its mission.

Occupational Safety and Health Review Commission (OSHRC)

OSHRC adjudicates disagreements resulting from citations issued to employers for noncompliance with OSHA standards. Employers may appeal decisions by OSHRC judges to the U.S. courts.

Mining Safety and Health Review Commission (MSHRC)

This agency has a very similar role to OSHRC. Employers can appeal citations for violation of MSHA standards. Employers can appeal MSHRC decisions to U.S. courts.

4-8 OTHER DEPARTMENTS, AGENCIES, AND SAFETY PROGRAMS

Many departments and agencies not listed above have safety programs for their own employees or contractors. For example, the *U.S. Army Corps of Engineers* has detailed safety rules for Corps construction that contractors must follow.

By executive order of the president, all agencies within the executive branch must follow safety laws and regulations.

Under the OSH Act of 1970, states may choose to operate programs to protect the safety of workers under federal guidelines or allow the federal OSH Administration to operate such programs within the states. Similarly, states may choose to operate their own Environment Protection Agency following federal guidelines.

States often establish laws, regulations, and standards and operate enforcement agencies to protect the safety of their citizens with regard to many kinds of products, operations, and services. Some estimate that states generate far more safety and health laws and standards than does the federal government.

EXERCISES

1. Find a safety or health regulation from the CFR on:
   - **(a)** ladders for construction
   - **(b)** ladders and walking surfaces affixed to truck trailers
   - **(c)** elevators in mines
   - **(d)** hazardous waste disposal
   - **(e)** windshields in automobiles
2. What is the public law number for:
   - **(a)** the OSHA Act of 1970?
   - **(b)** the Resource Conservation and Recovery Act of 1976?
3. Find announcements of proposed changes to safety regulations, schedules for public hearings or final rule adoption in recent issues of the *Federal Register*.
4. Do a literature search on a safety and health topic using the Internet. If possible, identify if the sources of information are reliable.
5. Find out what publications the Consumer Products Safety Commission offers for baby cribs. Do the same for infant car seats.
6. Find rulings of the Occupational Safety and Health Review Commission and the Mine Safety and Health Review Commission.
7. Find out whether your state operates a state plan for occupational safety and health. Or one for environmental protection. Compare the state regulations to those issued by the corresponding federal agencies.

REVIEW QUESTIONS

1. Describe differences and similarities between federal laws and federal regulations.
2. By what means are federal or executive branch agencies required to meet safety and health laws and regulations?
3. What is the main difference between civil and criminal law?
4. What is the *U.S. Code*?
5. Describe the methods used to label Acts of Congress.

6. What is the *Code of Federal Regulations*? How is it indexed?
7. What is the *Federal Register*? What is its significance for safety and health information?
8. What is the name of each federal agency identified below? Is it an independent agency? What safety and health responsibility does it have?
   - **(a)** GAO
   - **(b)** NIST
   - **(c)** PHS
   - **(d)** NIOSH
   - **(e)** FDA
   - **(f)** OSHA
   - **(g)** MSHA
   - **(h)** BLS
   - **(i)** FAA
   - **(j)** FRA
   - **(k)** FHWA
   - **(l)** NHTSA
   - **(m)** MTB
   - **(n)** EPA
   - **(o)** FEMA
   - **(p)** NTSB
   - **(q)** CSB
   - **(r)** NRC
   - **(s)** OSHRC

NOTES

1 http://uscode.house.gov/

2 www.archives.gov/federal-register/cfr/

3 www.osha.gov/

4 http://catalog.gpo.gov/F

5 www.bna.com/about-bna-a4760/

6 www.jjkeller.com/shop/Home

7 www.usa.gov/Agencies.shtml

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TOMPKINS, NEVILLE C., *A Manager's Guide to OSHA*, Crisp Publications, Menlo Park, CA, 1993.

CHAPTER 5

OTHER SAFETY LAWS AND REGULATIONS

5-1 INTRODUCTION

The federal government is not the only organization producing various forms of safety and health rules. State and local governments issue many such rules and standards. Companies produce rules for their own operation and products. Professional societies, associations, and laboratories develop rules and standards for adoption and use by others. Some work within consensus or voluntary standard-setting bodies. In addition, foreign governments, and international organizations create safety and health rules and standards.

It is impossible to list all rule- and standard-making organizations and keep up with their changes. This chapter includes some major organizations.

5-2 STATE GOVERNMENTS

State governments and their agencies issue many laws and regulations and have agencies assigned to enforce them. States may have agencies that enforce federal regulations.

Federal Programs Administered by States

For some laws there is an attempt to keep the federal bureaucracy from growing too much. The laws encourage states to administer federal laws and regulations. Federal funds often defray administrative expenses. Examples are state-operated environmental protection agencies and occupational safety and health agencies. Often states have not chosen to set up agencies and left enforcement with the federal government for their states.

State Laws and Regulations

The list of laws and regulations that can apply in a state can get quite complicated. Table 5-1 lists safety and health regulations commonly issued and run by states.

States have their own laws and administering agencies for many aspects of safety and health. Some state laws and enforcing agencies were in effect before federal safety and health laws were created. Others appeared after federal laws were enacted. In some cases federal laws and regulations supersede state laws and regulations, but not always.

To complicate matters, state and local governments may adopt the codes and standards of other organizations. The ordinances may not always remain current with changes in the adopted codes. Some ordinances may conflict or differ from state and federal laws and regulations. In some cases, all levels may apply or those of higher governments levels may supersede local ones. Not only are the laws and regulations confusing, but the methods and procedures for compliance may be as well.

Most states have regulations dealing with safety of life and the structural safety of buildings. They also have regulations for the safety of construction and industrial operations. Most regulate transportation, including vehicles, highways, and waterways. All states have regulations governing the licensing of occupations that can affect public safety and health. Most have standards or codes for sanitary systems and fire protection. State web sites have directories of state agencies, codes of state laws, and other information.

Local Governments

Most villages, cities, and counties have safety and health laws of some kind. Frequently, local governments adopt national standards or portions of them as part of local ordinances. Typical laws and codes at the local level also address safety and health issues. They include zoning codes, building codes, fire codes, plumbing and sewer codes, and traffic codes. Major cities commonly have unique regulations and codes.

5-3 PRIVATE COMPANIES

Most companies have rules about safety and health for employees, customers, products, and use of equipment. These may take several forms: policy statements, rule books, operating procedures and manuals, assembly or maintenance

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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TABLE 5-1 An Incomplete List of Safety Laws and Regulations Commonly Issued or Adopted by State Governments

Building
Building code
Guarding of floor and wall openings
Separation distances between structures
Gasoline stations
Institutions, hospitals, schools
Public assembly places
Residences, hotels, apartments
Restaurants, dance halls
Theaters, movie houses
Fire-resistant construction
Emergency lighting
Exits
Fire alarm systems
Fire extinguishers
Sprinklers and other fire protection equipment
Flame retardant finishes and materials
Electrical code
Access for the Disabled

Construction Regulations
Asbestos removal
Demolition work
Excavation work
Material hoists
Steel erection
Storage of construction materials
Temporary electrical wiring

Equipment and Machinery Regulations
Boilers
Elevators, dumbwaiters, escalators
Ladders
Mechanical power transmission apparatus
Painting and spraying equipment
Personal protective clothing and equipment
Proximity to high voltage lines
Tank truck vehicles
Welding and cutting equipment
Woodworking machines

Fire Safety Regulations
Blasting and explosives
Flammable liquids
Hazardous materials
Housekeeping and maintenance of work areas

Health Regulations
Air and water pollution control
Employee toilet, washroom and eating facilities
Lighting of work areas
Radiation control
Exposure to chemical and physical agents
Ventilation and dust control
Right-to-know/hazards communication

Industry Safety Codes
Mining of coal, metals and other materials
Dry cleaning and dying
Liquefied petroleum gas
Petroleum refining, handling, storage and transport
Railroads and grade crossings

Licensing and Qualifications of Occupations
Boiler inspectors
Engineers
Health-related professions
Mine inspectors
Field safety representatives for workers' compensation insurance companies
Safety professionals and industrial hygienists

manuals, agreements with unions, contracts, or agreements with suppliers and buyers. These rules may deal with employee activities or they may deal with procedures for certain kinds of work. Examples are procurement, selection, and training of workers, settling of grievances, or operation of particular equipment. There may be handbooks or reference manuals for design that include specific safety information. Special rules may exist for fire, transportation, weather, and other emergencies. Publications may be guides for customers or users.

If a company or organization hires a contractor to do work, it is critical to identify protections for contractor employees. A contract should state which safety and health laws, regulations, standards, rules, and procedures apply to the contractor and the work provided.

5-4 VOLUNTARY AND CONSENSUS STANDARDS

There are many non-government organizations that develop and publish standards for their field of interest. A few organizations specialize in the creation and publication of standards.

Committees of individuals create or update standards. The committee members usually represent the interest of companies or organizations sending them. Sponsoring organizations are usually members of the organization that will publish a standard. Several organizations may publish the same standard and work together on it.

There have been challenges to voluntary standards. This can occur when committee members have the interest of their own companies or products in mind and there is no open participation by the public. Challenges also relate to prescribing requirements in the standards that only participating product manufacturers can meet.

Standards created or published by most standards organizations are *voluntary standards*. One reason for this is that membership in the organizations that sets the standards is voluntary. Another reason is that compliance is often voluntary. Because the standards include those elements that at least a majority of committee members can agree upon, the standards are *consensus standards*. Compliance with voluntary and consensus standards is optional.

Compliance becomes required when a local, state, or federal governments adopts it or someone cites it in a contract.

Standards and Codes Organizations

Two of the largest voluntary standards organizations are the American National Standards Institute (ANSI) and ASTM International.

American National Standards Institute ANSI[1] publishes standards on a wide range of topics, including safety and health. ANSI is the standards organization in the United States that participates with the International Organization for Standardization (ISO).[2] ISO publishes standards that individual countries may adapt and enforce.

ANSI does not endorse the content of its standards. It merely provides a format, developmental and administrative procedures, and publishing service. Volunteer committees representing parties interested in a standard's subject matter write the contents. Other organizations sponsor some ANSI standards. For example, the American Society of Safety Engineers[3] develops several safety and health standards under ANSI as does the American Industrial Hygiene Association.[4]

ASTM International This standards organization formerly was called the American Society for Testing and Materials (ASTM). It operates much like ANSI, using volunteer committees from among interested companies, associations, and others. ASTM International publishes more than 12,000 standards. Some involve safety and health matters.

National Fire Protection Association NFPA[5] is an international standards organization that focuses on fire and other life quality-altering hazards. It issues codes and standards important in safety. Some well-known ones are the *Life Safety Code* (NFPA 101), the *National Electric Code* (NFPA 70), and the *Flammable and Combustible Liquids Code* (NFPA 30).

Building Codes Organizations As a result of historically important fires in Boston, Chicago, and other cities, each community began writing building codes for construction. Maintaining the codes grew more complex. That led to several regional building code organizations. Cities adopted the regional codes. Today there are two major organizations offering building codes that local governments can adopt. One organization is the NFPA. The other is the International Code Council (ICC). The NFPA building code is *NFPA 5000*, which links to other applicable NFPA standards. The primary ICC building code is the *International Building Code*. In addition, ICC has codes and standards for building systems, structures, and other elements. It is not easy to know which codes and standards apply to a local construction project. A builder must check with the local community, county, and state to determine which codes apply.

Professional Societies

Many professional societies have developed standards on matters related to their fields. Some organizations sponsor ANSI and ASTM International standards. Others professional societies maintain and publish their own standards. For example, the American Society of Mechanical Engineers (ASME)[6] has published its boiler and pressure vessel code since 1914, along with other standards. Also, SAE International, formerly the Society of Automotive Engineers, publishes many standards[7] related to automobiles, trucks, and other vehicles. Table 5-2 is an incomplete list of professional societies and organizations that produce standards related to safety and health.

Trade Associations

Trade associations promote the common interest of their members. Many associations exist for a wide range of fields and interests. Some associations develop standards for products or operating procedures. These standards can address safety and health topics. Some organizations may provide testing services.

The Safety Equipment Institute (SEI)[8] offers testing and certification services for a wide range of personal protective equipment.

Case 5-1 provides another example. The Association of Truck Trailer Manufacturers publishes many standards for a variety of truck trailers.

5-5 PRIVATE LABORATORIES

Private laboratories exist to offer independent testing, certification, and other technical services to customers for a fee. Some laboratories originally were set up to support the needs of the insurance industry. A well-known independent laboratory is the Underwriters Laboratory (UL).[9] Another independent laboratory is now the FM Global Center for Property Risk Solutions, a part of the FM Global insurance organization.

Underwriters Laboratory Incorporated

Underwriters Laboratory Incorporated is a nonprofit organization that conducts scientific investigations, studies, experiments, and tests related to hazards of life and property. As part of its role, it publishes standards, classifications, and specifications aimed at reducing hazards. It evaluates and tests products. It authorizes UL recognitions of tested products that comply with its standards. UL is best known for testing and certification of electrical equipment. Its services extend to fire-related and other products.

TABLE 5-2 An Incomplete List of Professional and Technical Societies that Have Developed Voluntary Standards and Codes

Abbreviation	Professional and Technical Society
ACGIH	American Conference of Government Industrial Hygienists
ACI	American Concrete Institute
AHRI	Air Conditioning, Heating and Refrigeration Institute
AIChE	American Institute of Chemical Engineers (and its Center for Chemical Process Safety (CCPS))
AIHA	American Industrial Hygiene Association
AISI	American Iron and Steel Institute
ANS	American Nuclear Society
API	American Petroleum Institute
ASA	Acoustical Society of America
ASABE	American Society of Agricultural and Biological Engineers
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASQC	American Society for Quality
ASSE	American Society of Safety Engineers
AWS	American Welding Society
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
ISA	The Instrumentation, Systems, and Automation Society
ITE	Institute of Traffic Engineers
SAE International	Society of Automotive Engineers International
SOLE	International Society of Logistics

Factory Mutual Global Center for Property Risk Solutions

FM Global's Center for Property Risk Solutions provides research on industrial fire, explosions, electrical, and other hazards and systems. It issues publications on results of this research and tests fire protection devices against its standards for the manufacturers of the devices.

Other Testing Laboratories

There are other testing laboratories dealing with safety and health. OSHA has a program called the Nationally Recognized Testing Laboratories (NRTL).[10] The program gives recognition to laboratories it finds acceptable.

Other laboratories test industrial hygiene exposure samples. The American Industrial Hygiene Association

CASE 5-1

A worker climbed to the top of a semi-tank trailer to close a fill port. While stepping from the walkway onto the access ladder at the rear of the tank, the worker fell to the ground. Multiple injuries slowed the recovery. The worker began to receive workers' compensation for time away from work. Then he filed a lawsuit against the truck trailer manufacturer.

The case was complicated by various facts. Some of the facts related to the condition of the worker's shoes. The worker had stepped in some material that spilled on the ground during loading and his shoes became wet. The material had stuck to the worker's shoes.

There were questions about the design of the access steps and the change from the walkway. There was no handhold easily reached from the walkway to aid in the change.

A safety expert became involved in the case. Part of the issue was establishing which standards existed for access to tank trailers. First, the expert checked the Department of Transportation regulations of the Federal Motor Carrier Safety Administration. There were no specifications for access and walkways for tank trailers.

The expert then turned to the trucking industry. Among the lengthy list of standards of the Association of Truck Trailer Manufacturers he found detailed standards for access equipment. The expert relied on the facts of the case and these standards to formulate opinions in the case.

(AIHA) operates an independent activity to accredit laboratories providing these services. Their organization is the AIHA Laboratory Accreditation Programs, LLC.[11]

5-6 FOREIGN AND INTERNATIONAL LAWS AND REGULATIONS

Foreign governments and organizations issue laws, regulations, and standards for safety and health. They may impact companies doing business or selling products where they have jurisdiction.

One international standard setting organization is the International Organization for Standardization (ISO). Its members are standards organizations in countries throughout the world. Most are standards organizations within individual countries. Its member organization from the United States is ANSI.

There may be regional safety and health standards. The European Union (EU) provides an example. Member countries jointly issue standards and guidelines on a wide range of topics. Some involve safety and health, some are mandatory but others are not. Individual countries usually handle enforcement.

There are also efforts to make standards in different countries uniform. This is called *harmonization*. In Europe, several organizations attempt to harmonize standards, including the ISO. Other examples are the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), the European Telecommunications Standards Institute (ETSI), the International Electrotechnical Commission (IEC), and the International Telecommunication Union (ITU).

International Organization for Standardization (ISO)

ISO standardization impacting safety, health, and environment management begins with ISO 9001 which covers quality management systems in general. Individual companies achieve certification if auditors find compliance with the standard.

ISO expanded the ISO 9001 concept to more specific areas of business involving safety, health and environmental matters. Key standards are

ISO 14001	Environmental Management Systems
OHSAS 18001	Occupational Health and Safety Assessment Series

More than 200,000 companies have adopted ISO 14001. OHSAS is changing to a standard on management systems related to ISO 9001. The new standard will be called ISO 45001, the Occupational Health and Safety Management Standard.

Chapter 35 will discuss additional details about safety management systems and these standards.

The European Union (EU)

In the EU, a *directive* is a legal act that is binding on member states. Member states may adopt stricter rules when adopting a directive into their laws. *Guidelines* are non-binding documents which aim to help implement directives.

The most significant directive involving safety and health is a general directive[12] (Directive 89/391/EEC) on safety and health at work. There are also individual directives on specific aspects. The general directive covers the following:

- the OSH Framework Directive;
- workplaces, equipment, signs, personal protective equipment;
- exposure to chemical agents and chemical safety;
- exposure to physical hazards;
- exposure to biological agents;
- provisions on workload, ergonomic and psychosocial risks;
- sector-specific and worker-related provisions.

There is also an EU directive on product safety (2001/95/EC), also called the General Product Safety Directive (GPSD). It covers consumer products not covered by other directives for specific sector products, such as toys, chemical, cosmetics, and machinery.

Individual Countries

As well as adopting regional safety and health laws and regulations, individual countries may create their own. There may be safety and health standards issued by a standards organization within a country. There are also government laws and regulations that apply to workplaces and products.

The United Kingdom and the Commonwealth Countries

It is worth discussing the workplace safety and health concept developed and implemented in the United Kingdom. Some of the Commonwealth countries, particularly Australia, have adopted this concept as well. The concept reduces the amount of regulation for safety and health details by the government. The concept relies on risk analysis and the hierarchy of controls (see Table 3-2) for companies, employers, and workers. It contrasts with the approach in the United States in which government agencies, such as

OSHA, write detailed implementing standards for workplace safety. The UK concept places a stronger enforcement burden on those involved in workplaces and less on government enforcement.

Lord Robens Report In 1970, the UK Parliament established a committee on Safety and Health at Work, and the chairman was Lord Robens. The 1972 Committee Report, often called the Robens Report, was lengthy and made recommendations for regulating safety and health in the workplace. When implemented, the report created a shift from industry-specific regulations to framework legislation. It shifted the focus of regulations from prescriptive requirements to process and outcomes-related duties of care. The report suggested that safety and health at work cannot be ensured by a continually expanding body of legal regulations and an ever increasing group of inspectors.

Risk-Based Safety Legislation for Workplace Safety and Health The end result was an approach based on risk analysis that extends all the way to the worker level. The analysis leads to decisions at any level being driven by making work safe. That leads to a safety management system, covered in more detail in Chapter 35.

Australia adopted this approach with the National Occupational Health and Safety Strategy in 2002. The strategy involved the Commonwealth, six states, and two territories. A publication by Safe Work Australia illustrates how to manage workplace safety and health under the overall approach.[13] The implementation extends to worker levels using risk analysis and the hierarchy of controls. Figure 5-1 provides an example of a worker-level card to help in decision-making.[14]

EXERCISES

1. Determine if ANSI or ASTM has safety standards for:
   - **(a)** stepladders
   - **(b)** floor slipperiness
   - **(c)** sports equipment
   - **(d)** glass for doors and windows
2. Determine if your state has any of the following:
   - **(a)** fire code
   - **(b)** ventilation code
   - **(c)** plumbing code
   - **(d)** construction safety regulations
   - **(e)** regulations for asbestos removal projects
   - **(f)** regulations for cleanup of contaminated soil
3. Find out which agency in your state is responsible for each of the items in Exercise 2.
4. Determine if your local government has a building code, fire code, zoning ordinance or waste disposal ordinance. Get a copy of each and identify which provisions are safety related. Find out how the local government enforces its ordinances and codes.
5. Skylights in roofs allow daylight to enter interior portions of buildings. When workers are on a roof, a skylight can become a working surface on which people may stand, walk or set items. Find organizations which may produce standards for skylights. Determine what safety considerations they include for skylight design, placement, installation or maintenance.
6. Identify organizations which write standards for indoor air quality.

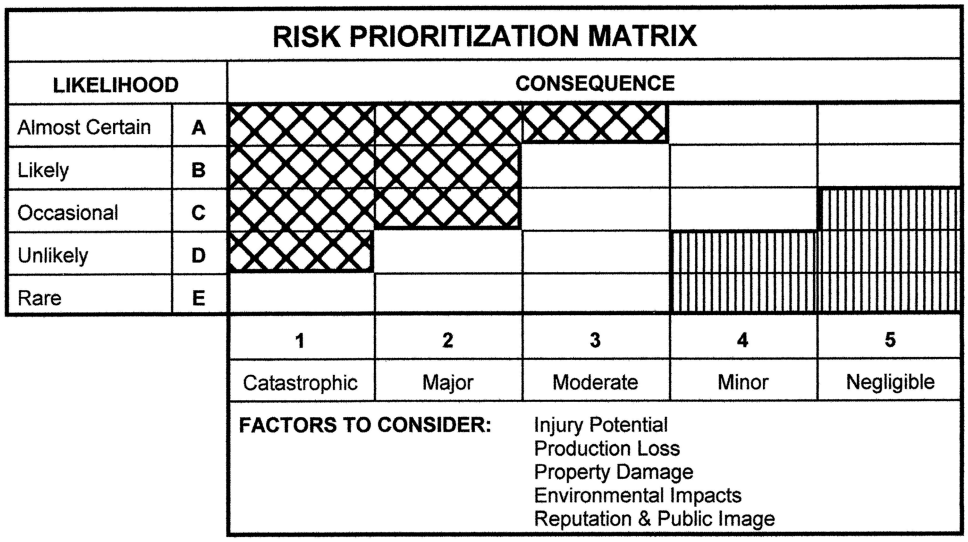


Figure 5-1. Example of a risk decision matrix used at a work group level.

7. Locate major sources of internationals standards for occupational safety and health.

REVIEW QUESTIONS

1. Where would one look to determine which agencies in a state are responsible for promulgating and/or enforcing fire codes, occupational safety and health standards, and traffic codes?
2. How would one find associations that may have developed safety and health standards?
3. Name three major organizations that publish voluntary standards, including safety standards.
4. Name two major safety testing laboratories.
5. Describe the general process usually used to develop voluntary standards.
6. What is the (1972) Lord Robens Report? Explain its major provisions and impacts on management of workplace safety and health.

NOTES

1 www.ansi.org/

2 www.iso.org

3 www.asse.org/cartpage.php?link=standards

4 www.aiha.org

5 www.nfpa.org

6 www.asme.org

7 standards.sae.org

8 www.seinet.org/

9 http://ul.com

10 www.osha.gov/dts/otpca/nrtl/

11 www.aihaaccreditedlabs.org/Pages/default.aspx

12 https://osha.europa.eu/en/legislation/directives

13 *How to Manage Work Health and Safety Risks: A Code of Practice*, Work Safe Australia, December 2011. Available at: www.safeworkaustralia.gov.au/sites/swa/about/publications/pages/manage-whs-risks-cop

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CHAPTER 6

WORKERS' COMPENSATION

6-1 THE DEMAND FOR WORK INJURY COMPENSATION

With the spread of the industrial revolution, the toll for workers rose rapidly. The toll claimed human lives and caused injuries, medical expenses, and lost income. The men, women, and children employed in factories faced many dangers. Society found these results unacceptable and pushed for reform to make jobs safer. They also sought to place at least some burden on employers to pay for the losses workers experienced. However, common law defenses thwarted those efforts while protecting employers. If a worker wanted to get compensation or indemnity under common law, the worker had to sue the employer. The worker had to prove that the employer's negligence was the sole cause of injury. The employee carried virtually all the risks in employment. Furthermore, an attempt to win compensation through a lawsuit was likely to result in loss of employment or create ill will.

Common Law Defenses

In compensation lawsuits, employers could claim there was no negligence on their part. They could also use three other common law defenses in a case involving an injured worker. The defenses were:

1. assumption of risk
2. contributory negligence
3. the fellow servant rule.

Assumption of Risk The principle of tort law called assumption of risk says that if a person voluntarily assumes a risk and becomes injured as a result, the person cannot receive indemnification (compensation) for the losses. This principle provided the employer near absolute protection against claims for work-related injuries of employees. By accepting a job, an employee assumed all the risks the job entailed.

Contributory Negligence If a plaintiff could prove negligence on the part of an employer and show assumption of risk as an inadequate defense, an employer could claim contributory negligence as an alternate defense. For example, assume an employee got caught in a machine and became injured. The employer could claim that the employee acted carelessly (was negligent) and, therefore, had no reason to bring action against the employer. At worst, the employer might have to pay some compensation if both parties were negligent.

Fellow Servant Rule When assumption of risk and contributory negligence were not enough, employers often used a third line of defense. Under common law, servants (employees) had certain duties toward each other. An employer could try to show that a fellow employee was negligent and caused the injury of a coworker. For example, suppose one worker fed material into a machine and another worker removed the material after the machine completed some action on it. Suppose also that the first worker accidentally started the machine and thereby injured the hands of the second worker. The first worker was negligent in a duty of care for the coworker and caused the injury. The employer was not responsible for the injury.

Early Workers' Compensation Laws

Following the industrial revolution, society found the stout defenses of the employer unacceptable. As a result, employees achieved compensation claims more frequently. Amount of awards grew larger. Societies in the industrialized nations of Europe and in the United States sought better ways to resolve job-related injury compensation. Near the dawn of the twentieth century, employers were ready for a change. A means for providing workers' compensation emerged. The United States followed the lead of Germany and England.

Early legislation tried to increase employer responsibility by removing some of the common law defenses: assumption of risk and the fellow servant rule. Some liability laws also changed contributory negligence to comparative negligence and allowed juries to determine whether the employer or employee was more negligent. Under Employer Liability Acts, the injured worker had to take his claim to court. The worker had to find fellow workers who would risk

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their jobs to testify for him. The worker would need to avoid being coerced by the employer to sign a release from liability for an inadequate payment. The employers began to lose cases and pay larger awards. The Employer Liability Acts, though an improvement, were still not fully adequate.

Workers' compensation laws followed and several states and the federal government passed them. Courts declared initial laws unconstitutional over issues of due process and mandatory participation by employers. State laws that followed were primarily elective laws. Employers could elect to come under the law. The first constitutionally acceptable workers' compensation law was passed in 1911. Since then, all states have passed such laws. States continue to change laws to include more workers, to extend and modify benefits, change administrative procedures and restructure benefit methods. States also look to reduce workers' compensation costs to compete for employers.

6-2 WORKERS' COMPENSATION LAWS

A No-Fault Concept

ln workers' compensation laws, employers and employees struck a balance in rights. Workers gave up the right to sue employers for compensation for injuries arising out of and in the course of employment. Employers agreed to provide compensation for work-related injuries as a cost of producing products or services. Employers were no longer liable for negligence resulting in worker injury. Legal battles were no longer required to determine who was at fault. Workers' compensation became a no-fault legal concept.

Proliferation of Laws

There are at least 53 separate workers' compensation laws in the United States. Attempts to standardize compensation laws or create federal standards for them have not progressed very far. Each of the 50 states has its own workers' compensation law.[1] Some states change their laws to reduce the overall costs for employers in comparison to neighboring states. That is a strategy to entice employers to relocate in their state or to stay there.

The federal government has three compensation programs, each covering a different group of employees. The three acts are the Federal Employees Compensation Act (FECA), the Longshoremen's and Harbor Workers Act, and the District of Columbia Workmen's Compensation Act. In addition, there are laws for special work illnesses, such as the Black Lung Benefits Act (BLBA). It provides monthly payments and medical benefits to coal miners totally disabled from black lung disease arising from employment in or around the nation's coal mines.

There are many differences among workers' compensation laws. Changes occur continuously. An annual report[2] summarizes the changes in provisions, benefits and changes.

Types of Laws

Today there are two major types of workers' compensation laws: compulsory and elective. A compulsory law requires each employer that is under its jurisdiction to accept its provisions and provide specified benefits. Under an elective law an employer has the right to accept or reject participation. If an employer rejects compliance with the law, the employer loses the three common-law defenses and becomes virtually defenseless. In effect, elective laws are compulsory. Most early workers' compensation laws found constitutional were elective. Nearly all are now compulsory for employers.

Goals of Workers' Compensation Laws

There are at least six goals for workers' compensation programs:

1. Replace lost income and provide medical treatment promptly.
2. Provide a single remedy without costly litigation and delays.
3. Relieve public and private charities of financial drain.
4. Encourage employer interest in accident reduction and prevention.
5. Restore earning capacity and work capability of workers through rehabilitation.
6. Encourage open investigation of accidents to prevent similar occurrences in the future (not to find fault).

One could debate whether existing compensation laws achieve their goals. For example, some thought that employers would become more interested in safety by becoming responsible for indemnification of injured workers. However, the competition among insurance companies for employers' business may have done as much to increase employer interest in safety. Many insurance companies selling workers' compensation insurance provide loss control services to employers. Preventing work-related accidents helps employers reduce claims and lower insurance premiums.

Workmen's Compensation versus Workers' Compensation

Until the 1970s, workmen's compensation was the accepted term. Workers' compensation is now the accepted term because it does not infer gender.

6-3 WORKERS COVERED

Today workers' compensation laws cover about 90% of all wage and salary employees. Some laws exclude certain categories of workers from protection. The exceptions vary among the different state and federal laws. Most common exceptions are domestic servants, casual (short-term, temporary) laborers, agricultural or seasonal farm laborers, volunteer workers, and workers covered by other laws (railroad and maritime workers). The laws exclude most professional athletes because they often have injury compensation clauses in their contracts. In many states, employers with fewer than two to five employees are also exempt. Under most laws, employers may elect to cover excluded employees voluntarily. In some states, exempted workers must agree with an employer who elects coverage voluntarily.

In the past, states have avoided jurisdictional problems by not requiring public employees of local government units to have workers' compensation insurance. Now most state laws require insurance for all public employees, whether career, elected or appointed.

Most workers' compensation laws cover minors. The definitions of a minor vary slightly. Some states consider minors below minimum age as illegally employed. For them. the law may require maximum compensation benefits at double or triple the standard rates. This provides a penalty for the employer and accounts for lost future earning capacity of the minor. An employer may face additional penalties under the law if an illegally employed minor becomes injured on the job.

6-4 ELIGIBILITY AND BENEFITS

Eligibility Criteria

The main goal of workers' compensation laws is to compensate workers for injuries caused by accidents *arising out of and in the course of employment*. This goal creates several issues about eligibility: What is an accident? What is an injury? What does "out of and in the course of employment" include? There are many interpretations to these questions.

Accident and Injury As noted in Chapter 3, the term accident suggests an event of very short duration. This was the meaning for early interpretations under workers' compensation claims. For most workers' compensation laws today, *accident* may refer to extended exposures and recognize other factors. ln the early 1980s, claims increased significantly for cumulative trauma injuries. These disorders result from repeated trauma to the part of the body affected, such as the arm of a carpenter swinging a hammer. More recently, claims for various forms of "job stress" have been on the rise.

The term injury originally included only physical damage to the body, such as cuts, punctures, fractures, and burns. Today most laws recognize a variety of job-related illnesses as a form of injury. Policies do not cover all job-related illnesses.

To avoid these language problems, different terminology is now in place. For example, the Federal Employees Compensation Act states that injured employees will receive compensation for "the disability or death of an employee resulting from personal injury sustained while in the performance of his duty." It defines injury to include "a disease proximately caused by the employment."

Employment There are many legal questions about the definition of employment. Laws exclude self-inflicted, intentional injuries, and injuries resulting from willful misconduct, often including those resulting from intoxication. The laws usually exclude most injuries resulting from personal conflict with a fellow worker and injuries occurring off the job.

Many difficulties remain. The courts must answer these questions on the merits of individual cases and the applicable law. For example, are workers covered while going to and from work? Are they covered during lunch hours? Are they covered when intoxicated while performing job-related tasks, such as a salesman wining and dining a customer? Is a heart attack at work covered? Is a worker covered when injured in a boating accident or baseball game at a company picnic?

It is difficult to establish if certain kinds of injuries occur during employment. For example, hernias, back injuries, and diseases with a latency period between exposure and observable symptoms all create problems in eligibility. A worker may file a claim stating that the injury was job-related and occurred on the job. Diagnostic procedures may not be able to establish the time or place of injury to verify whether it was job-related. Many of the laws have special provisions to deal with these problem cases.

Types of Disabilities

Most workers' compensation laws recognize four classes of disability: temporary total, permanent partial, permanent total, and death. Some states recognize an additional class: temporary partial. Definitions for and interpretations of each class vary by compensation law.

Temporary Total Disability Temporary total disability applies to a worker who is completely unable to work for a time because of a job-related injury. Eventually, the person recovers fully and returns to full job duties. No disability or reduction in work capacity remains after recovery. Most disability cases are temporary total cases.

Temporary Partial Disability This classification applies to injured workers who cannot perform their regular job duties during the recovery period. They can work at a job requiring lesser capabilities. Following recovery, the worker returns to work with full capability.

Permanent Partial Disability This classification refers to a worker who endures some permanent reduction in work capability, but is still able to keep gainful employment. There are two main classes. One is the loss of a body member, such as a hand, eye or finger. The other is the loss of use of a body member. Examples are a permanent reduction in vision in an eye or permanent reduction in the movement or functionality of an elbow or other joint.

Permanent Total Disability This refers to a worker injured on the job and no longer able to work, even after medical and rehabilitative treatment. Some states classify certain disabilities as permanent total disability by definition. Defined impairments typically include loss of both eyes, loss of both legs, and loss of both an arm and a leg.

Benefits

Workers compensation laws provide payments for medical expenses, burial expenses, loss of wages, and impairments. Most provide payment for physical and vocational rehabilitation. Some provide for mental rehabilitation.

Loss of Wages Injured employees receive compensation for their loss of earnings, which can occur under all the disability types. Most laws provide a percentage of the average weekly earnings of the injured employee. Payment schedules usually have upper and lower limits. Because disability income is not usually subject to income tax, a claimant receives only a portion of regular earnings. The percentage (commonly 66 2/3%) may vary by type of disability, number and ages of dependents and other criteria. Some states limit loss-of-wage payments to a maximum length of time (usually for temporary total disability). A few pay the difference between pre-injury wages and post-injury wages when the injury reduces the earning capacity, but not the ability to have gainful employment. A worker with permanent total disability may receive payments for life. In the event of a job-related death, the dependents of the worker usually receive benefits for loss of income until a spouse remarries or dies, and minor children reach adult age or complete school.

All workers' compensation laws require a waiting period before loss of wage payments begin. This waiting period ranges from one to seven days. However, if the disability extends long enough (usually two weeks), then compensation starts on the first day of lost wages. The purpose of this waiting period is to reduce administrative costs for minor disabilities and to discourage malingering by workers. Malingering is exaggerating or feigning injury or illness to escape duty or work. In addition, many employers offer sick leave benefits that typically cover the workers' compensation waiting period.

Medical Expenses Workers' compensation payments normally cover unlimited medical expenses found necessary in the treatment of the injured worker. These payments include physician charges, hospital costs, physical therapy, cost of prosthetic devices, and many other medical costs. There is no waiting period before payment of medical expenses.

Burial Expenses All compensation laws provide an allowance or fixed payment for burial expenses. The allowance varies. Some laws provide an additional allowance for transportation of the deceased if the death occurred away from the home employment location.

Rehabilitation Expenses There are two main kinds of rehabilitation. Physical rehabilitation involves therapies intended to regain lost strength and movement. Vocational therapy involves regaining lost work skills or learning new skills. Most workers' compensation benefits typically cover physical rehabilitation as a medical expense. Provisions vary for vocational rehabilitation. Some states require the employer to pay for vocational rehabilitation. Some laws have maximum payments, limit the period allowed for training or limit total expenses per case. Under the Federal Vocational Rehabilitation Act, states receive federal funds to help cover the cost of retraining persons disabled in industrial accidents.

Payments for Impairments Workers who sustain permanent partial disabilities receive compensation for the loss of a body member or the loss of its function (loss of use). The basic idea is a disability impairs an individual's ability to work and earn an income. As a result, the injured worker will earn less over the rest of the working years. In most states, payments for impairments are in addition to payments for loss of earnings during the period of healing.

Amount of Compensation

There are multiple theories for determining the amount of compensation. Three major ones are the whole-man theory, the lost wages theory, and loss of earning capacity. One or more of the theories may apply under a particular law.

Whole-Man Theory The whole-man theory considers only the functional effect of the loss—its impact on normal functions and abilities. The theory defines disability as a percentage of a whole, fully-functional person. A formula

that relates degree of disability to income potential defines the disability payments. For example, in Nevada, compensation is ½% of a person's average monthly earnings for each 1% of disability.

Lost Wages Theory The lost wages theory considers the actual loss in wages compared to a standard that estimates what the individual would have earned. When actual earnings are less than the standard and the reduction in earnings is due to the impairment, the actual compensation will maintain the income at or near the standard.

Loss of Potential Earnings Theory The loss of potential earnings theory is by far the most common approach for paying compensation for impairments. Future earning capacity derives from such factors as impairment, age, occupation, gender, and education. The benefits are the difference between pre-injury earnings continued into the future and estimated future earning capacity following injury.

Schedule Payments

The administrative problem of evaluating each permanent partial disability has given way to the widespread practice of schedules. Schedules set in advance the value of each kind of disability. Units for disability are weeks of lost earnings. For example, under the Federal Employees Compensation Act, the schedule says complete loss of a thumb is worth 75 weeks. Compensation is the number of weeks multiplied by the normal weekly wage of the person prior to injury. Practices in using schedules vary by state and the value of a scheduled loss can be quite different in different states.

Expressions for functional impairments or loss of use are a percentage of total loss of the member or its function. An impairment is the schedule value multiplied by the percent of impairment. For example, a 20% loss of use of a thumb in the preceding example would be worth 15 weeks (20% of 75 weeks).

Duration of Disability

Most compensation laws use calendar days to compute the period of disability. The period does not include the day of the injury and the day an injured worker returns to work. All days between the injury and the return to work are calendar days of disability. This avoids the problem of establishing the schedule that a person would have worked. Calendar days avoids difficulties in computing benefits created by swing shifts, variable work schedules, flexible hours, holidays, plant vacations, layoffs, and the other work schedules.

Average weekly earnings are the basis for computing loss of wages and payments for impairments. Sometimes monthly earnings determine death benefits. Many individuals have biweekly, monthly or annual pay rates and conversions to weekly rates could affect actual payments. Each compensation law has its own procedure for computing time and rate conversions.

6-5 FINANCING WORKERS' COMPENSATION

Types of Insurance

Depending on the law, a state may provide one or more methods to employers for workers' compensation insurance. The methods may include state-operated insurance, private insurance policies, or self-insured benefits. Only a few states require employers to participate in state-operated insurance. More than twenty operate a state insurance fund, but permit employers to purchase private policies from commercial insurance companies. Most states do not operate an insurance fund. Most states allow employers to be self-insured if they qualify.

Large corporations may reduce administrative costs by becoming self-insured. Group self-insurance arrangements may also be possible and allow smaller companies to benefit from self-insurance. To become self-insured, a company must create a large reserve fund to assure payment of claims. Self-insurance programs often include a wide variety of employment types to avoid concentrating risks. Many companies cannot afford to create the required reserve fund because the funds may have better uses elsewhere in the company. Also, reserve funds are not always deductible for tax purposes, whereas insurance premiums usually are. In addition, self-insurers must maintain medical, legal, and safety staffs to administer the program, resolve problems, and work to reduce claims.

Cost of Workers' Compensation

U.S. employers spend more than $100 billion per year for workers' compensation insurance of all types. Although costs will vary, about one-fourth of the payments are for medical care. Nearly half pays for compensation payments. Less than a third apply to administrative costs and expenses for safety and health and legal services provided by insurers.

Premiums

Employee payroll forms the basis for workers' compensation insurance premiums: Units for premiums are dollars per $100 of payroll. Average costs are about $2.00 per $100 of payroll, but vary widely with employment type.

The National Council on Compensation Insurance (NCCI), an actuarial organization, sets basic premium rates for most states. NCCI adjusts rates to keep up with changes in compensation laws. Each state has its own rate table or book.

Tables include premium rates for many kinds of operations or work activities. Rates for each state reflect different risks, and claim histories are accounted for in setting rates.

The system for classification of operations or work activity used to be the Standard Industrial Classification (SIC) system. SIC codes did not handle many new kinds of work and international commerce. In 1997, the United States adopted a new system called the North American Industry Classification System (NAICS).[3] Some kinds of work had to have major changes in classifications.

The total premium paid by an employer can be the result of a complicated procedure. If an employer has one kind of operation, the premiums result from the rate for that operation. If there are two or more kinds of operations, the operation with the largest amount of payroll usually sets the premium. If employees participate in several operations, the highest rated activity will determine the premium for those employees. For large, complex companies, combinations of rates usually determine the premiums.

Kinds of Rates

Depending on provisions in applicable compensation laws, there are multiple methods that may set premium rates for an insurer's customers. The key methods are manual rating, schedule rating, experience rating (prospective and retrospective), fixed rates, and premium discounts.

Manual Rates In manual rates, one applies premiums directly from the rate book for the applicable state. The premiums will be the same from all insurance companies. For example, a company engaged in sheet metal work has a payroll for the year of $853,200. Assuming all employees are sheet metal workers and the manual rate is $4.48 per $100 of payroll, the annual premium would be $853,200 × $4.48/$100 = $38,223.36.

Schedule Rates In the earlier days of workers' compensation, employers could receive a percentage reduction in the premium rates by engaging in certain hazard reduction activities. Those activities will appear in a schedule. This technique is no longer used. A major reason is the difficulty and expense in monitoring compliance.

Experience Rating: Prospective Under this method the accident experience of a policy holder can influence future premiums. To avoid excessive fluctuation in the premiums, the method uses a three-year experience period. The results of an immediate past year will affect the premiums three years later.

Each state determines the average losses by employment classification (such as meat packing, carpentry, or other crafts). The average rate times the payroll for that category in a company determines the expected losses. If the actual losses for an employer exceed that expected based on state average loss rates, the insurance will add a surcharge to the manual rate. If the actual losses are less than expected, the insurance will give a credit to the manual rate. The surcharge or credit is called the experience multiplier, the experience modification, or the experience rating modifier. This method provides an incentive to control and reduce losses.

Suppose the sheet metal firm above has experience rating modifiers during the three previous years of 1.32, 1.04 and 0.88, respectively. It would pay $38,223.36 × 1.32 = $50,454.84 for its premiums next year, $38,233.36 × 1.04 = $39,752.29 the following year, and $38,223.36 × 0.88 = $33,636.56 two years later.

Experience Rating: Retrospective In a very similar method employers with sufficiently large policies can affect their rates while the policy is in force. They do not need to wait for three years. Before a policy starts, the employer and the insurer agree to a set of adjustments in premiums within upper and lower limits. Claim experience will affect premiums during the life of the policy. Normally a policy life is one year, since buyers renew insurance policies annually.

Fixed Rate Premiums For small companies that cannot qualify for experience rating modifiers, the manual rate in effect at the start of the policy applies. The premium will change from year to year, depending on the losses of all businesses within the state for that employment classification.

Discounts

Premium Discounts For large policies, administrative costs are less than for small policies. As a result, states allow discounts for premiums in graduated steps based on total premiums paid. For example, there may be no discount for the first $1000 of premiums, 3% or more for the next $4000, and larger discounts for higher steps.

Competitive Premium Rates Until recently, workers' compensation premiums were the same for each program for each insurance company. All insurers quoted rates from the same manual rate book. Insurance companies used supporting services for clients to create a competitive edge. Recently, some states have started competitive premium rates in which insurance companies can set premiums on their own. Programs operated this way expect to produce lower rates, but often produce reduced loss control services.

Strategies to Reduce Workers' Compensation Costs

Today employers use a variety of methods to reduce workers' compensation claims and get injured people back to work. The employer, employee, and insurer all come out ahead.

One approach is dealing with the psychological and behavioral aspects of injured workers. Injured workers and their families develop fears and stress when not working after a workplace injury, even if temporary. Supervisors, co-workers, and company staff often treat injured workers differently after they file compensation claims. One goal is reducing supervisors' negative feelings and employers lack of concern. Back-to-work programs try to rebuild strained relationships and make workers want to return to work. They seek to rebuild the worker's confidence, particularly when a worker has lost some job capabilities.

Some employers use occupational health nurses and others to manage workers' compensation cases. The aim is to ensure effective administration of each case. Another is to maintain support for the injured worker during recovery.

Another approach involves systematic and objective evaluation of the injured worker's capabilities and job requirements. Special programs then rebuild their physical strength and endurance through work hardening. The programs may also change the workplace for reduced work capabilities or to prevent recurrence of injuries. The programs may help workers develop new job skills. Many hospitals now have worker rehabilitation programs that undertake interdisciplinary evaluation and treatment for workers' compensation cases.

Some states now require safety committees with participation by both management and labor. Building a cooperative environment and a team effort to reduce hazards and risks often lowers the number of incidents and claims.

In some large, multi-contractor construction projects, the project management firm or owner may use reductions in worker compensation claims to reward those contractors who meet project safety goals.

6-6 ADMINISTRATIVE PROCEDURES

Efficient administration of workers' compensation programs keeps cost down. These "no fault" programs relieve many of the delays in making compensation available to injured workers. Employers must tell employees about workers' compensation benefits and claim procedures and must keep records of claim-causing or potentially claim-causing injuries (usually other than first aid cases).

To initiate a workers' compensation claim, a worker must provide the employer with notice (usually written on a standard form) about the job-related injury. Employers often help with procedures because they know about injuries that happen on company premises. Once an employee files a notice, the employer must file a claim with the insurance carrier and with the state agency (if it is not the carrier). Often employers submit reports of on-the-job injuries with insurance claims. After review and approval of a claim, the insurance company authorizes and issues payments. In some cases a physician must determine the kind and level of disability. The American Medical Association publishes guidelines[4] to help standardize patient evaluations and medical decisions.

Most payments result from direct settlement. The insurer pays benefits at the prescribed rates. In some cases the employer and employee reach an agreement on the benefits (subject to state approval) to get funds disbursed. Usually there is no dispute between employee and employer. In a third method, a commission or its representative reviews each claim to determine benefits. When employees feel that the compensation offered is inadequate, under most programs they may file an appeal within a certain period (normally 1–3 years). Injured workers contest only 5–10% of the five million or more cases each year. Each program has established procedures for reviewing cases and proceeding toward final resolution. There may be several levels of appeal and an employee may engage an attorney in claim and appeal procedures. Many states have established approved fee structures for legal work in workers' compensation cases.

6-7 THIRD PARTY LAWSUITS

A workers' compensation case automatically involves two parties: the employer and the injured employee. In some cases, either party may file a lawsuit about the case against another company or person. The additional company or person is a third party.

As noted earlier, employees cannot file a suit against their employers for job-related injuries. However, an employee may sue the manufacturer of a machine or product that caused injury. An employee may sue another employer on a multi-employer job site or another organization or individual involved in the injury-causing accident. In a few states, an employee can sue a fellow worker. After the legal theory of strict liability appeared, the frequency of third party suits increased. Chapter 7 explains this legal theory. Most often the suit is against a manufacturer of a product causing the injury or another organization contributing to the accident and injury.

In some cases defendant manufacturers or other employers may file a lawsuit against the injured worker's employer. Ultimately, the worker's employer may have to pay part of the settlement.

If an injured worker wins a third party lawsuit and receives an award that is larger than that obtained through workers' compensation, the worker may have to repay the compensation obtained through workers' compensation. The

employer can place a lien against the third party award to assure repayment of workers' compensation benefits.

If the third party award is less than that obtained through workers' compensation, the employer may only have to pay the difference between the third party award and the amount paid by workers' compensation alone. All such adjustments would occur after payment of legal and other direct expenses for the suit. If the worker fails to win a third party award, there is probably no loss in workers' compensation benefits.

Third party lawsuits by injured workers are not the only means for achieving payment other than workers' compensation for job-related injuries. Under certain conditions, the employer may file suit on its own behalf or that of the employee against a third party. If the suit is for the employee, any award greater than workers' compensation benefits and expenses necessary to bring the suit pass to the employee.

6-8 WORKERS' COMPENSATION ORGANIZATIONS

A wide range of specialists and professionals work with workers' compensation cases. There are administrators, adjudicators, physicians, safety and health professionals, occupational and vocational therapists, attorneys, actuaries, risk managers, financial specialists, human resource specialists, legislators, and others.

Many participate in workers' compensation organizations. Table 6-1 is an incomplete list of workers' compensation organizations. Their publications and resources provide details about workers' compensation laws, management, and operations. Most states have government agencies implementing workers' compensation laws.

TABLE 6-1 Incomplete List of Workers' Compensation Organizations

American Association of State Compensation Insurance Funds (AASCIF)
American Bar Association (ABA)
American Medical Association (AMA)
Association of Industrial Accident Boards and Commissions (AIABC)
Association of Workers' Compensation Boards of Canada (AWCBC) - Canada (CA)
Association of Workers' Compensation Professionals (AWCP)
International Association of Industrial Accident Boards and Commissions (IAIABC)
National Academy of Social Insurance (NASI)
National Association of Workers' Compensation Judiciary (NAWCJ)
National Council of Self-Insurers (NCSI) – Workers' compensation
National Council on Compensation Insurance (NCCI Holdings)
Self-Insurance Guaranty Funds of America (SIGFA) - Workers' compensation
The Risk Management Society (RIMS)
Workers' Compensation Claims Association (WCCA)
Workers' Compensation Insurance Organizations (WCIO)
Workers' Compensation Research Institute (WCRI)

In 2013, the National Institute for Occupational Safety and Health (NIOSH) created the Center for Workers' Compensation Studies.[5] It sponsors educational conferences and research linking workers' compensation with preventing worker injury and illness.

6-9 WORKERS' COMPENSATION AND INSURANCE FRAUD

Some have reported 1–2% of workers' compensation claims involve fraud. Such cases add to the cost of providing legitimate benefits to injured workers. Some cases involve one individual. Others involve several individuals working together. Fraud may involve claimants, employers, medical and health care providers, or attorneys.

Claimant fraud may involve:

- malingering or exaggeration of symptoms;
- working while allegedly disabled and not reporting income;
- claiming a job-related injury that never occurred;
- claiming an old injury as one that occurred on the job;
- claiming a non-work injury as a work-related injury;
- falsifying mileage reports.

Employer fraud may involve:

- under-reporting payroll used to calculate premiums;
- classifying employees to lower insurance premium positions;
- deducting premium dollars from employee's wages;
- employer knowingly fails to have necessary workers' compensation coverage.

Medical and health care provider fraud may involve:

- providing unnecessary testing or treatment of injured workers to reap financial benefit;
- inflated injuries;
- phantom injuries;
- illegal kickbacks;
- fake clinics;
- billing for services or treatment never performed;
- billing the workers' compensation insurer and the workers' health insurer for the same services.

Legal services fraud may involve:

- bogus lawsuits;
- illegal kickbacks.

CASE 6-1

Insurance fraud can become an elaborate scheme involving many people. Some involved in a workers' compensation case may prefer doctors who give favorable decisions on disabilities and preferred attorneys who route injury cases to them. Fraud extends to other kinds of insurance. The following case illustrates the possible complexities.

In August 2003, a grand jury indicted 567 individuals and corporations in one of the largest insurance fraud scams in US history. The ring staged more than 1,000 car accidents and collected more than $500 million from the insurance industry.

The pyramid scheme indictment involved 300 crash dummies. They were the passengers who got at least $500 plus a portion of any bodily injury settlement.

There were 12 runners. They recruited crash dummies and orchestrated accidents. Medical clinics paid them $1,500 or more per accident "victim."

The scheme involved 243 physicians and other medical personnel. They billed insurance companies up to $50,000 per victim for diagnostic tests, treatments and other services.

There were shell companies that collected millions in insurance payments and laundered the money.

Indictments included 12 attorneys and accountants who had masterminded the scheme and controlled many management companies.

EXERCISES

1. Find out what the manual rate is for your state for:
- **(a)** paint manufacturing
- **(b)** grocery store workers
- **(c)** roofing work
- **(d)** traveling carnival workers

2. For the occupations in Exercise 1, try to find out what the rates are for one or more neighboring states.

3. Get a copy of the workers' compensation regulations for your state and a neighboring state. Compare such factors as benefits paid for different disabilities. Compare procedures for submitting, processing, and appealing claims.

4. Discuss fairness of benefits and cost of workers' compensation premiums with:
- **(a)** a local attorney who deals in workers' compensation
- **(b)** a local business executive
- **(c)** a workers' compensation insurance broker or agent

5. Find out what the job duties are for a person who is a loss control representative for an insurance company.

6. Visit a rehabilitation facility at a local hospital or clinic that helps get injured workers back on the job. Find out how they approach minimizing workers' compensation claim costs.

7. A grain elevator is considering a location for a new plant. It must choose a site in your state or one or more neighboring states. All employees will fall into two job classifications, listed in the following table with expected annual payroll for each classification. Find out the current manual rates in order to complete the table below.

Job classification	Total annual payroll ($)	Manual rates for.		
		Your state	1st adjacent state	2nd adjacent state
Grain elevator operator	2,500,000			
Truckman	850,000			

- **(a)** If the company will pay manual rates for the first three years, what is the total cost of premiums during the three years for each of the possible sites?
- **(b)** Compared to the site with the highest premium rates, how much can the employer save during three years at each of the other sites?

8. The company in Exercise 7 had the following experience rating for all job classifications:

Year	Rating
1	0.92
2	0.87
3	1.21
4	1.02

If there is no change in the manual rates over the four years, what workers' compensation premiums will a company in your state pay for each of the four years following the initial policy?

REVIEW QUESTIONS

1. What are the three common law defenses that used to protect employers from legal claims for compensation resulting from on-the-job injuries?
2. When were constitutionally acceptable workers' compensation laws first passed in the United States?
3. What agreement did employers and employees reach under the no-fault concept of workers' compensation? What did each party get?
4. What are the two types of workers' compensation laws?
5. How many workers' compensation laws are there in the United States?
6. What is the basic qualification to receive workers' compensation?
7. What was the original term for workers' compensation?
8. Which employees are often exempt from workers' compensation benefits?
9. What qualifies a worker for workers' compensation?
10. What are the four most commonly used classifications for disabilities? Define each.
11. What benefits do workers' compensation programs normally provide?
12. What are schedule payments?
13. Describe theories used to calculate payments for impairments.
14. Name methods for establishing workers' compensation premiums. Briefly explain each.
15. How can an employer reduce workers' compensation claims?
16. How can an employer reduce workers' compensation premiums?
17. What is a third party lawsuit? How can it result from a workers' compensation case?
18. How is NAICS used in pricing workers' compensation premiums?
19. Identify parties who often are involved in workers' compensation. What behaviors or actions by each party are fraudulent?

NOTES

1 www.statelocalgov.net/50states-workers-compensation.cfm

2 *Analysis of Workers' Compensation Laws*, Chamber of Commerce of the United States, Washington, DC, annual.

3 www.census.gov/eos/www/naics/

4 *AMA Guides to Work Ability and Return to Work* and *Guides to the Evaluation of Permanent Impairment*, 6th ed., American Medical Association, Chicago, IL.

5 www.cdc.gov/niosh/topics/workerComp/CWCS/

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Hood, Jack B., Hardy Jr., Benjamin A. and Lewis Jr. Harold S., *Workers Compensation and Employee Protection Laws in a Nutshell*, 5th ed., West Publishing, St. Paul, MN, 2011.

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CHAPTER 7

PRODUCTS LIABILITY

7-1 INTRODUCTION

Safety professionals and designers need to understand the basics of products liability law. Knowing the legal theories and claims processes will help avoid unnecessary lawsuits against manufacturers, distributors, and resellers. It will help when defending products against lawsuits. It will improve risk analysis for products from planning and design, all the way through packaging, distribution, sales, and use.

Industrial, commercial, and consumer products are a significant source of injuries and death. Injured parties frequently sue manufacturers and those in the distribution chain for compensation. It is estimated there are more than 100,000 products liability lawsuits in courts in the United States each year. Since about 1970 when there was a change in products liability laws, there has been a major increase in products liability lawsuits.

Today there is growing pressure to reform products liability laws. The goal of some reform is to reduce the economic burden for manufacturers and other businesses. One kind of reform is limiting the size of any legal award. Another is making those filing a claim responsible for legal costs if a case is frivolous.

Products liability litigation is one means for society to cope with the technological risks imposed on it. In the past, buyers carried most of the risk for use of products. The changes in products liability law shifted much of the responsibility to manufacturers and suppliers. They acquired a greater role in ensuring that products are safe.

Decisions and actions of engineers, managers, and others during planning, design, manufacturing, distribution, and marketing of products can impact their safety. Knowledge of the legal concepts and processes for seeking remedies helps engineers to act prudently, professionally, and ethically. They can identify risks in their products during planning and design and not let risks reach the marketplace.

7-2 THEORIES OF LIABILITY

A manufacturer or seller of a product is not liable for all injuries that may result from a product. That would be absolute liability. However, in most states, three theories of liability apply to products and establish the duties of a manufacturer or seller toward a user or consumer. The three theories are: (a) warranty; (b) negligence; and (c) strict liability. A lawsuit may involve more than one legal theory.

Warranty

Warranty addresses the performance of a product on implied or expressed claims made for it by the manufacturer or seller. A buyer expects a purchased product to perform its functions. That is implied warranty. Warranty is part of contract law and the relationships between buyers and sellers.

Express warranty derives from published or stated claims a manufacturer or supplier makes for a product. For example, suppose a supplier's catalog describes attributes of a product and says: "Absolutely safe." That would mean that under nearly any conditions, the featured product would not cause harm. That is an overstatement and a poor advertising statement today. It is important to check advertising statements made for a product. They may need changes to reduce risks.

Negligence

Negligence involves the conduct or behavior of a person or corporate body, something they did or failed to do. Suppose a manufacturer does not include safety features in a product that are marketplace standards. That may be a case of negligence. As noted in Case 7-2, suppose a manufacturer's representative gives improper advice about product use to a buyer's employee. That may be a case of negligence.

Strict Liability

Strict liability deals with characteristics of products that are unreasonably dangerous and defective. If the product causes harm to a user, there may be a violation of the strict liability concept.

Torts

The theories of negligence and strict liability are part of tort law. Torts are wrongful acts, injuries, or damages for which people bring civil (as opposed to criminal) action.

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 7-1

In a discovery deposition, attorneys asked the chief engineer for a manufacturer of warehouse storage racks what standards his company used to test the structural integrity of its products. The engineer replied: "I am not aware of any standards for that."

At issue was a lawsuit filed for a fork lift driver who had become a paraplegic. Apparently, large rolls of paper fell from a storage rack and struck him in the back of his head and neck when he backed into the storage rack.

Later in court the attorney for the driver presented evidence for his client. The attorney introduced information about a standard published by an association of warehouse equipment manufacturers. The standard included procedures for testing the structural integrity of storage racks under a variety of loading and use conditions. The attorney also presented evidence showing that the chief engineer's company was a member of the association.

Then, with the chief engineer on the witness stand, the attorney quoted the discovery question and answer for the jury. Imagine the credibility of the chief engineer who oversaw the rack design. Imagine the concern of his employer who manufactured the racks involved in the case. His technical knowledge failed. He did not know about the standards his industry had adopted that applied to his designs.

Caveat Emptor

Products liability developed from English common law. As the industrial revolution of the late 1800s placed new products on the market, the social and legal climate at that time gave them an esteemed position. The legal concept was *caveat emptor*—let the buyer beware. Manufacturers and suppliers ignored complaints about a product. The law held that a buyer was negligent for not examining a product for defects at the time of purchase.

Doctrine of Privity

A manufacturer was further protected by *privity of contract*, or the *doctrine of privity*. It limits the parties involved in a

CASE 7-2

While completing the set-up, a worker lost two thumbs in a casting machine. The machine made sand molds used to make castings. The machine had two metal bowls, one facing upward and one downward. Between the two bowls was a plate with a form on each side, the pattern. The two bowls came together around the pattern during the first part of an operation. During that phase, the bowls were filled with oiled casting sand and compressed the sand. Then, the bowls opened with the sand inside. When open, the machine withdrew the pattern. That left voids to be filled during casting.

In the second phase, the bowls filled with sand came together again in a step to get the complete sand mold out of the bowls. Plates that formed the base of each bowl held the sand together as the bowls opened. When fully open, the sand mold moved to a conveyer away from the machine. The mold moved to the casting area where molten metal filled the void.

During machine operations, two large guide pins kept the bowls aligned. During machine set-up, it was critical to make sure the bowls lined up correctly with the guide pins. If they did not, vibration would cause some sand to collapse into the void, creating a faulty sand mold.

A representative of the machine's manufacturer told the worker that the best way to test whether the guide pins aligned with the mold was to place a thumb on each side of the pattern plate. One could feel if there was correct alignment. The worker did that.

To complete the test, the worker told his co-worker to "drop the table." In machine-speak that meant lowering the bottom bowl. A rotary switch on a control panel managed the up-down movement of the "table." The coworker stood to the right of the "table" and turned the switch to lower the bowl. Instead, it went up and crushed the set-up worker's thumbs.

A second mold-making machine had the same layout, but the molds exited on that conveyor in an opposite direction. The control panel was on the left of the "table." The rotary switch on each control panel operated the same and had the same labels. Rotating right meant the table moved down. Rotating left meant the table moved up.

A lawsuit challenged the design, including the design of the switch. The rotary switch design involved a population stereotype that tied to the table motion. The population stereotype differed when the switch was on the left or right of the table. Having an up-down switch that moved up and down with the table motion regardless of location might have prevented the error by the co-worker.

negligence case to those directly involved in a transaction–the buyer and seller. As long as a manufacturer was not part of the direct selling of its product, there was no need for concern over suits from buyers. Retailers and dealers sell most products. There was little need for manufacturers to worry about defective and unsafe products. ln 1916, the decision in *MacPherson v. Buick Motor Company*[1] ended the privity doctrine for negligence cases and opened the door to changes in products liability law. The court ruled negligence occurred on the part of a remote (from the sales transaction) manufacturer of an automobile for a defectively made wheel that broke and injured the plaintiff. The court's opinion noted: "Without regard to a contract between buyer and seller and when a buyer is not likely to check a product for defects, the manufacturer of a thing of danger has a duty to make it carefully."

Similarly, a 1960 decision removed the doctrine of privity as a barrier in implied warranty cases.[2] The court held that a buyer is not capable of determining the fitness of an automobile for use. It also recognized that under modern market conditions, a manufacturer who places a product on the market and promotes its sale becomes a party to the sale through implied warranty.

Emergence of Strict Liability

In 1962, the theory of strict liability emerged. It removed the need to show breach of express warranty on the part of a plaintiff.[3] The court ruled: "A manufacturer is strictly liable in tort when an article he places on the market, knowing that it is to be used without inspection for defects, proves to have a defect that causes injury to a human being." In 1965, the American Law Institute published the Second Restatement of Torts (Section 402A). Most courts accept it as the rules for strict tort liability.

As a result of the changes in liability law, about 95% of all products liability suits now fall under the theory of strict liability. With these shifts in the law, society recognized that users and consumers often should receive compensation for injuries resulting from defective products. The legal pendulum swung from manufacturers, who had been virtually immune from liability, toward users and consumers. Adjustments in products liability continue as the courts determine if the pendulum has swung too far in favor of product users or not far enough. More recently, the use of negligence has increased. There is a growing effort to limit liability and to minimize frivolous products liability suits.

7-3 PRODUCTS LIABILITY EVIDENCE

The plaintiff in a products liability lawsuit must bring certain evidence in support of a claim. Except in expressed warranty cases, the plaintiff must prove:

1. the product was defective;
2. the defect existed at the time it left the defendant's hands;
3. the defect caused the injury or harm and was proximate to the injury;

Strict liability cases require no other evidence to establish the basis for a case. However, under negligence, there is a need for additional evidence. The plaintiff must also show that

4. The defendant was negligent in some duty toward the plaintiff.

In warranty cases, the plaintiff must merely show that a product did not meet implied or expressed warranty or represented claims for the product.

The defendant may use several defenses for the three kinds of evidence. The questions surrounding the existence of a defect in a product can be complex.

- The defendant may try to show that although the product is dangerous, the danger by itself is not a defect.
- The defendant may try to show that the plaintiff altered the product or unreasonably misused it.
- The defendant may claim that the product met accepted standards of government, industry or self-imposed standards related to the product, to the claimed defects, and to the use of the product.
- In addition, the defendant may try to show that the product did not cause the injury or was not the proximal cause.

7-4 NEGLIGENCE

Besides the three common elements of evidence just noted, a plaintiff acting in a negligence case must show that the defendant had a duty toward the plaintiff in providing a product free of the claimed defect and was negligent in performing that duty. Negligence includes acts of omission (failure to act) or commission (performing an act). Because negligence has to do with the behavior of an individual or organization, it is often very difficult for the plaintiff to gather enough information about the behavior of the defendant to prove negligence. It would be difficult, for example, to show what decisions a defendant made in the process of designing a product. It may be hard to find out how or why they were made. Such records may not exist. Similarly, without the defendant's records it would be difficult to portray a quality control program in manufacturing that was not implemented according to policy and standards for the batch containing the injury-causing product. Through discovery procedures, a plaintiff can seek to obtain such information about the

defendant if it exists. A plaintiff may try to prove that a manufacturer did not use the technology available when it made the product.

A defendant may claim that he had no duty toward the plaintiff or that he performed the duty without negligence. The defendant may argue that he met government, industry, consensus and standards of professional practice or even self-imposed standards applicable to the product or the defect. The defendant may try to show that the plaintiff was negligent in the use of the product (contributory negligence), which led to the injury. The defendant may also try to show that the plaintiff was fully aware of the defect and voluntarily accepted the risks associated with the defect in using the product.

Behavior of a defendant or plaintiff must meet a comparison to behaviors of a *reasonable person*. Negligent conduct occurs only when an act is less than that which a reasonable person would have done under similar circumstances. Creating the reasonable person standard opens the door for many legal arguments. There are arguments about the probability of preventing harm, the likelihood that injury will occur, how serious a resulting injury would be, and the cost of preventing injury from occurring.

7-5 WARRANTY

As noted earlier, there are two types of warranty: implied and express.

Implied Warranty

Through the Uniform Commercial Code, adopted by nearly all states, the user or consumer of a product receives some guarantee about the quality of a product. This is implied warranty. Implied warranty includes both (a) merchantability, and (b) fitness for a particular purpose. Merchantability means that a product fits the ordinary purposes for which people use such goods. Merchantability applies only to the sellers who normally deal in particular goods. Buyers assume that such sellers have knowledge about the products they sell. Buyers do not expect the same kind of expertise about a product when buying from a one-time seller.

The other type of implied warranty is fitness for a particular purpose. Before purchasing a product, a buyer may wish to know whether a product will perform for a particular application, not just in general. The buyer may ask the seller for advice or a recommendation. A buyer may ask a seller to select a suitable product. If the buyer purchased the product because of the seller's assistance and the product does not perform, there is a breach of implied warranty of fitness for a particular purpose.

Implied warranty is a branch of contract law rather than a tort. If injury results to the buyer from the intended use of the product, the buyer can act against the seller. The buyer and members of the buyer's household are the only persons who can bring a case against the seller. However, the buyer cannot act against the producer of the product under this theory.

Express Warranty

Express warranty occurs when a seller makes expressed claims or representations for a product that become a basis for the bargain. The plaintiff must show only that the product did not meet the seller's warranty or representations and that an injury resulted from the failure. The plaintiff does not have to prove that a defect or unreasonable danger existed in the product.

Advertising frequently creates express warranty. Overselling a product and making claims for characteristics it does not have can lead to products liability lawsuits. Consider a classic example. In the past, the purchaser of a new automobile relied on the manufacturer's claim that the windshield was shatterproof.[4] When driving the car, a stone struck the windshield and a fragment of the glass lodged in the plaintiff's eye, causing injury. The plaintiff received compensation in the case. The court ruled:

> [It would] be unjust . . . to permit manufacturers . . . to create a demand for their products by representing that they possess qualities which they, in fact, do not possess, and then, because there is no privity of contract existing between the consumer and the manufacturer, deny the consumer the right to recover if damages result from the absence of those qualities when such absence is not readily noticeable.

One problem associated with express warranty is trying to differentiate actual misrepresentations from overstatements of a product's qualities (called *puffing*) that buyers typically expect salespeople to make. In express warranty cases a jury must decide if there is misrepresentation.

7-6 STRICT LIABILITY

Negligence is difficult to prove. Warranty often restricts the parties involved in a case to buyer and seller. As a result, the theory of strict liability emerged in the early 1960s.

Operating under the Second Restatement of Torts, Section 402A,[5] a plaintiff in a strict liability lawsuit does not have to prove negligence. The behavior of the defendant is irrelevant. The defendant cannot show how well he operated his quality control or product safety program to prevent defects. A defendant cannot present how a quality design process created a safe product. Those may all be good practices, but they are defendant behaviors and do not apply in strict liability cases.

Also under strict liability a plaintiff does not have to prove breach of warranty. Strict liability focuses on the qualities of the product that caused injury. The plaintiff must present the three fundamental elements of evidence:

1. The product was defective.
2. The defect existed at the time it left the defendant's hands.
3. The defect caused the injury or harm and was proximate to the injury.

7-7 DEFECTS

There are three types of defects in a product. They are design, manufacturing, or inadequate warnings and instructions. Defects are conditions that an ultimate consumer does not contemplate and are unreasonably dangerous to the consumer.

Design Defects

Design defects are unreasonably dangerous characteristics of a product resulting from decisions, calculations, drawings, or specification of the design process. One can identify a design defect because it occurs in all products of a particular make or model. This identification rule distinguishes it from a manufacturing defect.

There are many factors in design from which defects may result. One factor is selection of materials. For a particular product, cost, durability, function, maintenance, appearance, and strength influence material selection.

Improper material selection can lead to a lawsuit. A plaintiff won a negligence case involving a ladder constructed of soft pine.[6] A consensus standard did not allow that material for ladder construction.

Another design factor involves management of energy. Applying the Energy Management Theory discussed in Chapter 3 may help during design.

A lawsuit provides an example. A baseball pitching machine depended on a spring to energize the arm and cause it to throw a ball. Even after unplugging the machine, the spring could be storing energy. A sudden, unexpected release might cause harm. Such a machine injured a boy's face. He recovered damages when vibration caused the catch holding the spring and arm to release.[7]

Providing functional features in a product is another important factor in design. Risk analysis and anticipating user behavior can help anticipate harmful design features and assure reasonable safety. For example, users could adjust an outdoor lounge chair to different positions. However, a court found a chair as unreasonably dangerous when a plaintiff severed a finger in the part of the chair's arm that moved during adjustment.[8]

A design must include safety features for removing hazards. A court found the design of an earth-moving machine defective because it did not have a rearview mirror as a safety feature. A mirror would allow the driver to see a blind area behind the machine when backing up. In the case the court considered a worker who stood in the blind zone. The operator backed over the worker causing injury. The plaintiff recovered damages from the manufacturer because there was no rearview mirror.[9]

An important factor to consider in design is the *use environment*. Use environment refers to the context for a product's use. What may otherwise seem safe, could become unreasonably dangerous when one understands the physical, social, and behavioral context for a product's use. During design, there needs to be an analysis of user behaviors and conditions in which they may occur. For example, it is likely that a storm door will withstand the impact of a rolled-up newspaper thrown by a delivery boy. The use environment includes such behavior. In another example designers should recognize that a child may use an oven door as a step to climb onto the counter top to get a cookie or something else. People who have raised children probably saw their child pull out a drawer or open the oven door to help with reach. Most people realize that oven doors are not intended for climbing. However, a designer who knows the use environment will consider such user behavior.

ln product design, it is important to comply with government and consensus standards. Lack of compliance may prove that a design defect exists. Standards are minimums and following them will not ensure adequacy of a design. The best protection is applying risk analysis and removing hazards through design. Designers should realize that there are standards beside published ones. They can include standards of practice. Standards of practice may be principles or practices appearing in textbooks or taught in courses or practices typically used in a discipline, operation, or a company.

Besides complying with standards, designers must stay abreast of technology, even that outside their specialty fields. Failure to use available technology in a design to improve safety may place unnecessary liability on a product. An important concept is *state of the art*. If other products include some safety technology or technical feature and a designer's product does not, there may be an increase in liability. A product that causes harm may have less liability if it uses known and available technology.

Manufacturing Defects

Manufacturing defects occur in a few products of the same make. Most manufacturing defects involve poor quality materials or shoddy workmanship. Some involve production irregularities and errors.

A way to identify a manufacturing defect is to sample like products. If all products of the same model have the same

defect, it is a design defect. If only some products of the same model and production run have the defect, it is a manufacturing defect. Manufacturing defects usually result from inadequate quality control, testing, and inspection or from errors in assembly. One example of a manufacturing defect is a poor weld that fails at a later time.

The legal doctrine of *res ipsa loquitur*—the thing speaks for itself—frequently applies to negligence cases involving manufacturing defects. Classic cases of manufacturing defects include exploding soft drinks bottles or food products containing foreign material, such as metal or glass.

Defects in Instructions and Warnings

A product may meet all necessary standards of design and contain no production flaws, yet it may be unreasonably dangerous. The third kind of defect involves instructions and warnings. A product that could cause harm should provide adequate instructions for use and warnings about dangers during use or misuse. Under both the theories of negligence and strict liability, a supplier has a duty to warn of dangers that remain in a product or occur during its use. See Chapter 35 for a discussion of risk analysis, hazard reduction, and protection for hazards which remain.

One must make a clear distinction between instructions (or directions) and warnings. Warnings identify dangers inherent to the product or dangers that may result from its use or misuse. Instructions explain how to use a product effectively or safely. Instructions explain what actions one must take to eliminate or reduce the likelihood of injury during use of a product.

There are many important characteristics for instructions and warnings. Effective instructions and warnings require use of good writing skills, knowledge of use environments, ergonomic principles and other factors. Table 7-1 lists 15 important characteristics of warnings.

A common error made when writing instructions is describing what a product does. Instructions require use of imperative statements that tell what to do. Instructions should explain what to do in a step-by-step sequence. Instruction should explain the order of steps.

When writing warnings, it is helpful to include reviews by legal experts, human factors specialists, users, and others. Writers and reviewers need to consider the user's level of education, reading skills and abilities and the user's language. Chapter 33 will discuss other characteristics of instructions and warnings, such as use of symbols, readability, population stereotypes, and using everyday language.

TABLE 7-1 Characteristics of Warnings

READABILITY. The ability to read or receive a message. Multiple languages, pictorials or symbols and Braille are all methods to ensure that a message is received.

UNDERSTANDING. The ability to understand individual components of a message. Some words are beyond the vocabulary of certain readers. Not all symbols are recognized or understood by every viewer.

COMPREHENSIBILITY. The ability to understand the overall message. Messages must be simply stated, require little technical or specialized knowledge and be precise.

PRACTICALITY. The ability to heed or comply with a warning in light of behavior that is normally expected or given a normal context for the warning.

EFFECTIVENESS. Having valid and reliable test data to establish whether a warning does, in fact, communicate its message and is not just assumed to do so by its writer or designer.

BEHAVIOR MODIFICATION. Achieving the behavior desired by the warning, that is, preventing unsafe or injury-causing acts that might otherwise occur.

COMPATIBILITY. Suitable for and consistent with expectations of individual applications. Warnings should agree with local customs and practices, be consistent in similar situations (standardized), meet requirements of consensus and local standards and be appropriate for a particular application situation.

CONSPICUOUS. Provide a reasonable certainty of perception, without search and in a short time. This characteristic includes size, color contrast, stimulus novelty, brightness level and other characteristics.

DURABILITY. The ability to resist environmental conditions, such as abrasion, wear, wetness, chemicals, sunlight, and so forth.

RELIABILITY. Must be present when needed. This property is particularly applicable to visual and audio warning devices that must act when a danger is present.

REINFORCEMENT. Giving people additional or more detailed data about a warning or its importance through training sessions, operating manuals or other means. The aim is to influence the receiver's sensitivity toward the warning.

DANGER SIGNAL. Attention-getting enhancements, such as underlined or boxed text, bright colors, signal words like danger or warning, special auditory tones, and so forth.

PLACEMENT. Locating warnings where they are likely to be seen or heard and where the danger is; proximity in distance and time.

NOVELTY. Use of attention-getting features like animation, voice synthesized messages, color, and so forth.

TYPE. Classification of purpose or function. For example, one might classify a warning as (a) advisory, (b) explaining what to do, or (c) a reminder.

Source: Derived from Peters (1984).

CASE 7-3

A company rented construction equipment. A rented aerial work basket tipped over, injuring its temporary operator. The operator drove the machine using controls in the elevated basket.

A mobile aerial work basket has counter-weights intended to prevent tip over in normal operating positions. The rental agency had repaired the machine. The repair required removal of the counter-weights. After fixing the machine, the agency replaced the counter-weights.

During the discovery phase of a lawsuit against the rental company and the manufacturer, experts found that the counter-weights were not exactly in their original position. Analysis determined whether the faulty repair contributed to the tipping of the machine. Considering the repair and all other facts of the case determined whether liability attached to the rental company, the manufacturer, the operator or all of them.

7-8 MISUSE AND FORESEEABILITY

In some products liability cases the supplier of a product may be liable even when someone uses a product for some purpose or in some manner other than intended. In cases of misuse, the courts use a test of *foreseeability*. This test determines whether a designer or supplier could foresee a possible misuse.

A classic case involving foreseeability is that of a child standing on the open door of a kitchen range to reach something in the cupboard and having the range tip over on him. Foreseeability involves anticipating the use environment, as described earlier.

A manufacturer must allow for foreseeable abuses and misapplication of a product. To reduce liability associated with misuse, a designer can provide warnings and instructions that address foreseeable misuses.

7-9 MODIFICATIONS AND SUBSTANTIAL CHANGE

One of the main rules of evidence says a defect must have existed at the time the product left the defendant for liability to exist. Sometimes a user or owner modifies or alters a product in some way during its life. A supplier has responsibility for those risks it introduced.

A supplier may have liability for some modifications introduced by a user. However, the one who modifies a product has liability for modifications. Failure to include an important feature, which then necessitates a user modification, may shift the liability to a manufacturer.

7-10 STATUTE OF LIMITATIONS AND STATUTE OF REPOSE

Another problem for a manufacturer is that of expected product life and its role in liability. Many states have laws that limit the period for filing products liability claims. These laws are called statute of repose or statute of limitations. A statute of repose sets a strict time limit computed from a deadline. Examples of deadlines are date of manufacture or date of sale. A statute of limitations is very similar, but triggered by the date of an injury. The time allowed for filing a claim under either type of law varies a lot. The time limit usually involves a fixed number of years from the trigger date.

One problem for a manufacturer is knowing the laws of each state. They are not alike. Not all states have both types of laws.

A typical problem for a product design is whether the product and its components will fail within the allowable period. The failure may lead to a lawsuit, especially if it causes injury.

7-11 THE LAWSUIT PROCESS

The procedures for a liability suit involve three main steps: complaint, discovery, and trial. Variations from this simplified model will occur in particular cases. Within each step other activities may occur and the entire process can end at any point. An additional step may involve pre-trial negotiations. Parties try to settle the case without a trial.

Several factors can impact the conclusion of a case. A defendant may find that a plaintiff has a good case. Parties may want to avoid legal costs and reach a settlement. A defendant may petition the judge overseeing the case for a summary judgment that removes the defendant from the case. A defendant may not want the arguments to become general knowledge through case law. Settling at any point prior to a jury decision will not place plaintiff or defendant information on record for potential access by others filing similar lawsuits.

The court and judge having jurisdiction in a lawsuit oversee the procedures of the case.

Complaint

In the first step, the attorney for the plaintiff files a complaint with the court that has jurisdiction. Before filing a complaint,

a plaintiff's attorney will conduct a significant investigation to decide if a lawsuit has a reasonable chance of success.

After the defendants receive a copy of the complaint, defense attorneys will usually deny the accusations. In suits naming several defendants, each defendant may file a petition. It will state why the plaintiff improperly cited the defendant in the lawsuit.

In some cases, a defendant may bring additional defendants into the case by filing additional complaints against them. This sometimes happens when an employee files a lawsuit against the manufacturer of a product that injured the employee. The manufacturer may sue the employer. Under workers' compensation law, an employee cannot sue an employer for an on-the-job injury.

There are several reasons for naming a person or organization as a defendant in a complaint: The potential defendants have a duty toward the plaintiff and may have a role in a defect causing injury to the plaintiff. Another consideration is the ability of the defendant to pay damages. A common term for a defendant with financial capability (through assets or insurance) to pay is *deep pocket*.

Discovery

In the discovery step, the plaintiff sends written interrogatories to the defendant, who may have to answer them in a certain number of days. The defendant may not have to answer them if they are unreasonable or cause unreasonable expense to prepare an answer.

Based on the complaint and written interrogatories, each party begins to develop its case by identifying witnesses who will testify in the case. Each party may question the opponent's potential witnesses under oath in discovery depositions. A legal reporter makes a record of the questions and answers. The attorneys depose the plaintiff and others who may have some knowledge related to the case. Attorneys will also depose expert witnesses, persons with specialized knowledge, such as doctors and engineers. These depositions focus on the experts' knowledge and opinions of the facts in the case.

During discovery, both sides develop a good idea whether they can win the case. If both feel they have solid arguments, the process continues into the trial step. If there is a good case but the issue revolves around which parties must pay, the case may also continue. If the plaintiff has a weak case, one or more defendants may petition the court for dismissal.

Pre-Trial

After completing discovery, a case may move to negotiations among parties. The defendant may offer compensation. The plaintiff may make a counter-offer or accept the initial offer. Negotiations may involve computations for such factors as the value of interruption or loss of employment, anticipated future expenses, and pain and suffering. If the parties agree on a settlement, they sign a formal agreement. Then the case is over. Most products liability cases end through pre-trial settlements. Some negotiations may actually continue as a trial begins.

Trial

In a jury trial, each side presents its arguments. Attorneys question witnesses once again under oath. Not all witnesses in the deposition step may appear at trial. An attorney may question a witness about statements made during a deposition. After each side completes arguments, the jury must decide whether the plaintiff should receive compensation. The jury must decide how much to award.

If the case involves the theory of comparative negligence (allowed in some states), the jury must decide the portion of negligence attributable to each party and apportion the total award accordingly. For example, a jury may decide a manufacturer has 20% of the total dollar value of an award, a user 50%, and the employer 30%.

7-12 EXPERT WITNESS

If the facts in a legal case involve specialized and technical subject areas, expert witnesses may testify in the case. A case may require the expertise of engineers, safety professionals and other specialists. For example, physicians usually testify about product injuries. In products liability cases, engineers often testify about a product, existence of defects, use of the product, design alternatives, negligence, compliance with published standards or standards of practice, the state of the art, and other matters.

Besides giving testimony, an engineer may serve other functions in a products liability case. An engineer may help the attorney understand the technology involved in the case and may help establish whether a defect existed through testing and evaluation of products, literature searches or other means. An engineer may help reconstruct the incident and help the attorney prepare interrogatories, locate standards and gather facts, and perform tests.

Before an engineer serves as an expert witness, the attorney doing the hiring will determine whether the potential witness holds qualifications in the area of specialization needed. The attorney will examine the candidate's training, experience, and professional credentials. Later, in depositions or at trial, the opponents may challenge the qualifications of the expert to testify on the subject matter in question.

Reasonable Person Concept

In products liability lawsuits, a common issue is comparison of the matters in a case to a reasonable person. Behaviors in cases may involve the question, "What would a reasonable

person or manufacturer do or know?" The concept applies primarily to negligence. There is a comparison between the conduct of a defendant and a norm. The norm is the reasonable person.

In some cases, experts will face a question involving a reasonable person. Attorneys will ask an expert whether a defendant should have known about something. Attorneys may ask if a reasonable person would have certain knowledge or would have acted the way a defendant did.

Degree of Scientific and Engineering Certainty

Ultimately, an attorney will seek technical opinions of the expert on issues in the case. Often sought are opinions "with a reasonable degree of scientific and engineering certainty." In a legal sense, this infers a certainty of 51% or greater. The question is whether the expert is more sure than not sure on an issue. It is not certainty in a statistical sense, where one uses a 95% or similar statistical confidence level in drawing inferences or conclusions from data.

7-13 LEGAL STRATEGIES

In some products liability cases, there are case models that help estimate costs, likelihood of success, and potential compensation for a plaintiff. Some of the models are sophisticated. Most result from collections of data from similar cases and use of probabilities. The models often account for the age of the injured plaintiff, the degree of injury, the medical diagnosis and prognosis for recover, and the ability to return to some form of work. Attorneys may use the models to decide if a case has potential for compensation. Attorneys may decide how far to proceed in a case before the cost of legal work exceeds the potential for financial recovery.

Another strategy is to prolong a case and to make the cost of litigation higher than the potential settlement. For example, a defendant's attorneys may find many experts for their case. During discovery the plaintiff's attorney may have to travel across the country many times to complete discovery depositions.

A common legal strategy is to find a way to discredit the witnesses of an opponent in a case. An attorney may focus on how much an expert earns from participating in a case. An attorney may challenge experience and education. An attorney may challenge an expert who has not designed a product similar to the product involved in a case.

7-14 INTERNATIONAL PRODUCTS LIABILITY LAWS

The developed countries have adopted some types of products liability laws and directives. Most occurred after tort reform in the United States. Some countries set liability limits to a fixed financial amount. Often the laws limit liability to manufacturers and importers.

A manufacturer with worldwide distribution may need the services of an international legal firm to deal with international products liability cases.

In some countries, experts work for the courts, not for a plaintiff or defendant attorney as is the case in the United States. That way, an expert's opinion applies to the entire case and all parties involved.

7-15 REDUCING LIABILITY RISKS

There are risks in any product. A manufacturer or seller of a product must face those risks in putting a product on the market. A manufacturer or seller cannot prevent a user from filing a lawsuit after injury from a product. However, liability does not mean absolute liability.

A manufacturer or seller can reduce liability in several ways. One approach is having effective products liability attorneys who provide strong defenses in the courts. A better approach is preventing claims in the first place. Engineers can prevent many lawsuits by defending the manufacturer in design, manufacturing, packaging, advertising and the marketplace.

For products liability the primary role of an engineer is to remove unreasonable dangers from products and prevent defects from reaching the marketplace. Eliminating risks in a product will reduce opportunities for lawsuits. Analyzing risks for a product and incorporating risk reduction in design will prevent most lawsuits. Products with few defects will produce few product injuries and even fewer liability claims.

Engineers must understand products liability laws and principles. Engineers must account for the use environment, foreseeable misuses, product life, possible product modifications, hazards, potential injury, seriousness of injury, compliance with standards (as a minimum), state-of-the-art practices, quality control, packaging and handling, advertising, and claims for products. They must face concerns like cost, function, maintenance, maintainability, and durability of a product. Engineers must see that warnings identify remaining hazards. They must help prepare instructions necessary for user protection. There are detailed programs and guides for managing these items in a systematic way.

A good technique for reducing hazards in a product is thorough design review. A review team not involved in the design, and thus having independent views and limited bias, can analyze a product for hazards and acceptable controls. The team may include engineers, attorneys, safety professionals, and others. The collective knowledge and experience of the team can provide a broad foundation of experience and expertise. The review team may work closely with the designers throughout the design process. If there are reviews after completing initial design, it is more costly to make

CASE 7-4

In 1982, a very popular, over-the-counter painkiller, Tylenol, became the vehicle for murder. Someone replaced capsules with cyanide-laced capsules that looked like the originals. The criminal, who was never caught, returned tampered containers to store shelves. Seven buyers died when they purchased and consumed tampered pills. The events led to a $100 million product recall and interrupted market share for a long time.

The overall result for consumers was a major change in packaging. Most food products today have tamper-resistant packaging. Products like Tylenol now have three tiers of protection. Glue holds shut the cardboard box containing a bottle of pills. To access pills, a user must remove a shrink-type band that holds the lid to the bottle. In addition, users must remove a foil seal that covers the mouth of the bottle after removing the cap. Even boxed breakfast cereals have glued boxes and heat sealed inner containers holding the cereal.

What was once a terrorist-style, random crime led to innovative and effective product protection. Not only is safety of a product important when reducing products liability, so is the design of packaging. Designers must consider ways in which someone can access edible or other kinds of products and prevent tampering before the products reach consumers.

design changes. Some call the review team an audit team. This is particularly true when the team reviews for compliance with laws, regulations, standards, and practices.

EXERCISES

1. Select a product.
   (a) Identify its primary use.
   (b) Try to identify possible product use environments.
   (c) Try to identify foreseeable misuses and the hazards involved.
   (d) Evaluate the product for product safety. Consider alternatives for design and manufacture that would reduce or eliminate its hazards.
   (e) Compare design alternatives in terms of risk, cost, function, product life, and other factors.
   (f) Prepare a set of instruction for users of the product.
   (g) Prepare a set of warnings for the product and its hazards and draft instruction for its safe assembly, installation or use.

2. Obtain the warnings and instructions accompanying some product. Identify uses and misuses for the product.
   (a) Determine whether the warnings adequately identify the risks for a user.
   (b) Determine whether instructions adequately tell users how to protect themselves from the risks.

3. Arrange with an attorney working on an actual products liability case or a law school holding mock proceedings to monitor the deposition of an expert witness or the conduct of a trial.

REVIEW QUESTIONS

1. What are the three theories of products liability?
2. Explain major differences among the three theories.
3. What is a tort?
4. What evidence must the plaintiff provide for each of the three theories?
5. Under which theory are most products liability lawsuits argued today?
6. What is absolute liability?
7. What is privity of contract or the doctrine of privity?
8. What is contributory negligence?
9. What is a defect?
10. What are the three types of defects? Give an example of each.
11. What is the difference between warnings and instructions?
12. Name at least five characteristics of warnings.
13. What is the doctrine of proximate cause?
14. What is *res ipsa loquitur*?
15. What does *caveat emptor* mean?
16. What is a statute of limitations? What is a statue of repose? How do they differ?
17. Explain the role of an engineer as an expert witness.
18. How can engineers reduce liability for a product?
19. What is the reasonable person test?
20. What is merchantability?
21. What is comparative negligence?
22. Explain the difference between implied and express warranty.

23. What does "reasonable scientific and engineering certainty" mean?

24. What are the main phases of a product's liability lawsuit? At what point in the process can a case conclude?

NOTES

1 217 New York 382, 111 Northeastern 1050 (1916).

2 *Henningsen v. Bloomfield Motors*, 32 New Jersey 358, 161 Atlantic 2d 69 (1960).

3 *Greeman v. Yuba Power Products, Inc*., 59 California 2d 57, 27 California Reporter 697, 377 Pacific 2d 897 (1962).

4 168 Washington 456, 12 Pacific 2d 409 (1932).

5 *Restatement (Second) of the Law: Torts*, American Law Institute, St. Paul, MN, 1965.

6 *Wilson v. Loe's Asheboro Hardware, Inc*., 259 North Carolina 660, 131 Southeastern 2d 501 (1963).

7 *Dudley Sports Co. v. Schmitt*, 279 Northeastern 2d 266 (Indiana App.) (1972).

8 *Mathews v. Lawnlite Co*., 88 Southern 2d 299 (Florida) (1956).

9 *Pike v. Frank G. Hough Co*., 2 California 3d 465, 85 California Reporter 629, 467 Pacific 2d 229 (1970).

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CHAPTER 8

RECORD KEEPING AND REPORTING

8-1 WHY KEEP RECORDS AND FILE REPORTS?

Pick up any significant book on business and management. Very likely, the author will emphasize the importance of data and performance metrics. Case 8-1 provides a synopsis from several business authors.

Data are essential to address prevention of accidents and incidents. Preventive, proactive, approaches are most effective (see Figure 3-6). However, there is value also in tracking the effectiveness of prevention (see Figure 3-5). There is always something to learn when something goes wrong.

Measurement of performance involves collecting data. Analysis of data helps gain insights and fosters learning. Results of analysis contribute to preventive plans and strategies.

Very early in life people discover experience is a good teacher. This idea also applies to safety and health. Understanding what happened in incidents and why they occurred can lead to preventive actions for similar situations. Records of incidents offer reactive strategies to improve safety performance. They are trailing indicators of performance. Many organizations also compile data on leading indicators of safety performance. Leading indicators measure actions that can prevent incidents. Chapter 35 will explore both types of metrics further.

There are many reasons for compiling records and preparing reports.

Improving Safety Performance

One reason for keeping safety records, analyzing the data, and preparing reports is to improve safety performance. Safety records provide metrics that show improvement or decline for safety. Without safety performance data, one cannot learn from incident experience. Learning from performance data is a management function. Reports help management set plans and create strategies for becoming better.

Rewarding Safety Performance

Many companies have award programs based on safety performance statistics. Without records and reports, these programs would be impossible. Statistics based on data provide quantitative indicators of safety performance.

Meeting Legal Requirements

Federal, state, and local governments require employers, manufacturers and others to maintain certain safety records. They may also require submitting certain reports. For example, employers must keep records of job-related incidents. Automobile drivers must complete a police incident report following a vehicle incident. Building owners must maintain records on maintenance and inspection of elevators. Later sections of this chapter will explore some of these record keeping and reporting requirements.

Protecting Legal Rights

Before someone can file a claim for workers' compensation benefits, there must be a record of the incidents causing harm. If there are no records of an on-the-job injury or illness, an employee would not have a valid claim.

A manufacturer may compile records about design decisions, production, testing, and sales of products. The records may provide defenses against liability lawsuits.

Gaining Business

In some businesses, safety performance data and records help gain a competitive advantage. Investors and business collaborators may consider safety performance as one factor in reaching business decisions with a potential supplier. Some government contracting procedures require bidders to include safety performance data as part of a bid package. A bidding company may not qualify at all if safety performance falls below some standard. Final selection and contract

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 8-1

What business authors say about metrics and measurement.

- Thomas Watson, founder of IBM, once said: "If you want to achieve excellence you can get there today. As of this second, quit doing less-than-excellent work."[a]
- There is one phrase that sets remarkable [organizations] apart from their counterparts, it's "Data, data, data." They gather information, analyze it, and then use it to become even better. They incorporate the findings into their strategic and operational planning.[b]
- TQM Principle #3, Prevention versus Inspection, directs attention toward the prevention of defective products and service [accidents and incidents], rather than the discovery of defects and deficiencies [hazards] after resources have been spent.[c]
- What you measure is what you get—what you reward is what you get.[d]
- Review each of the performance measures you use to manage your organization. Eliminate each of those measures that is not meaningful to the results of the organization. Remember, "What you measure is what you get." Ensure that every measure of performance is pertinent to the achievement of a goal or value of your organization. Otherwise, you risk misdirecting your organization.[e]
- If you don't have measurements, you can't make progress because you don't know where you are. Quite simply, everyone needs a scorecard.[f]
- All good-to-great companies began the process of finding a path to greatness by confronting the brutal facts of their current reality.[g]

[a]Tom Peters, *The Pursuit of WOW!*, Vintage Books, New York, 1994.
[b]*Measures of Success*, ASAE & The Center for Association Leadership, Washington, DC, 2006.
[c]Joseph R. Jablonski, *Implementing TQM*, Technical Management Consortium, Inc, Albuquerque, NM, 1994.
[d]Jack Welch, *Straight from the Gut*, Warner Books, New York, 2001.
[e]Peter F. Drucker, *The Daily Drucker*, Harper Business, New York, 2004.
[f]Greg Brue, *Six Sigma for Managers*, McGraw-Hill, New York, 2002.
[g]Jim Collins, *Good to Great*, Harper Business, New York, 2001.

award may depend on the overall safety history of the bidding company.

Setting Insurance Rates

Chapter 6 discussed methods for setting workers' compensation insurance premium rates. In some methods the cost to the insurer for claims made against a policy determine future premium rates. Insurance rates for liability or other business protections also influence premiums. Some people buying auto and home insurance encounter this after an accident or claim. Incident records and reports may also help determine the value of a loss.

Issuing Legal Penalties

Sometimes the severity of legal penalties, fines or terms of imprisonment result from record keeping, the lack of it, or data contained in records. Recurring injuries or illnesses may provide a basis for claims of negligence or willful wrongdoing by enforcing agencies. Employers who fail to maintain OSHA records properly may face fines that exceed one million dollars at a single facility.

Improving Hazard Recognition

Proactive safety strategies begin with hazard recognition. One difficulty is anticipating all possible hazards in a product or operation. Some situations are complex and incidents involve combinations of conditions that do not occur together often. By collecting data on incidents through investigations and studying them, one can often identify previously overlooked hazards. The investigative reports may uncover unrecognized combination of contributing factors.

Defining Corrective Actions

Hazard recognition leads to preventive actions. Safety plans and actions may depend on studies of incidents and accidents. Records of those cases help justify required protective actions. Reports to management may require use of funds to change processes or modify operations, facilities and equipment. Records from incidents and analysis of data may help justify requested changes and gain support for safety action plans.

Enhancing Safety Management Systems and Building Safety Cultures

What gets measured gets attention is the basis for many business strategies. Compiling data on safety metrics is an essential part of improving safety performance. Information from safety and incident records and reports may form the basis for ranking problems, ranking corrective actions, and assigning limited resources to achieve the greatest risk reduction.

Often overlooked are near-miss data. Some have found a way to use near-miss reports from operating units as a way to engage the units in improving safety performance and build a safety culture.[1]

8-2 KINDS OF RECORDS AND REPORTS

There are many kinds of safety records and reports. Laws and regulations require many of them. Some help create safety cultures. Others are plans to submit or have available for inspection. Examples are training plans or respirator management plans.

Record-keeping tasks continue to expand. Safety professionals may have responsibilities for their employers. Employers must keep records and file reports on incidents. They must also keep records on training, exposures, issue of safety equipment, conditions and tests of certain kinds of equipment, release of hazardous materials, and many other safety, health and environmental matters. Different requirements apply to various types of businesses, operations, activities, and equipment.

Much of the discussion in this chapter focuses on required record keeping and reporting. A review of some of the federal requirements offers an idea of the volume and complexity of record keeping and reporting tasks. Readers should obtain laws, regulations, and standards important for their employers or clients to make sure they track the right information consistent with current rules and procedures. The discussion in this section provides examples in four areas. Most involve trailing metrics.

Accident and Incident Reporting

The main types of records and reports required by the federal government for safety and health include work-related incidents. Some also cover transportation incidents, and incidents arising from use of radioactive materials.

Work-Related Incidents At least three significant government organizations require reporting of work-related incidents and injuries or illnesses. They are the Occupational Safety and Health Administration (OSHA), the Mine Safety and Health Administration (MSHA), and the Nuclear Regulatory Commission (NRC). Other federal agencies also have reporting standards.

OSHA requires[2] that each employer with more than 10 employees must maintain a log of recordable occupational injuries and illnesses. Also, each must create an annual summary by calendar year. In addition, OSHA requires a more detailed incident report of each recordable occupational injury or illness. Instructions for OSHA forms specify the data for the log, summary and supplementary records. Employers must have these records available for inspection and, when requested, submit them to the Bureau of Labor Statistics.

There are special rules for certain kinds of injury or illness or death and hospitalization. For example, should an employee die on the job or should three or more employees become hospitalized, the employer must report the incident to OSHA within 8 hours. Employers must report incidents involving excessive radiation exposure or release to OSHA if NRC rules do not apply. Section 8-3 provides additional details about OSHA record-keeping requirements.

MSHA requires that each mine operator submit mine accident, injury and illness reports.[3] There is one form for each injured or ill person. Mine operators must also submit quarterly mine employment and coal production reports. They show total employee hours worked in order to compute incident and injury statistics.

NRC requires a variety of records and reports.[4] Records include radiation protection programs, surveys, individual monitoring results, waste disposal, and other records. Some reports range from theft or loss of licensed material, notification of incidents, to reports of exposures, radiation levels, and concentrations exceeding limits.

For example, depending on severity, licensed operators of nuclear facilities and operations must report incidents to NRC. Reportable incidents are excessive exposures of workers to ionizing radiation, excessive release of radioactive material, loss of operation, and property damage. NRC requires immediate, 24-hour or 30-day reports, depending on the severity of the incident.

NRC requires immediate reports if one or more workers receive exposures exceeding the allowable quarterly dose by 20 times. The same requirement applies to releases of radioactive material 5000 times greater than allowed, loss of one working week of operation of a facility or $200,000 property damage.

Transportation Incidents The federal government requires reports for a variety of transportation accidents and incidents. Different agencies handle different transportation equipment.

Aircraft Operators of aircraft must notify the National Transportation Safety Board (NTSB) of all incidents and those incidents in which a flight control system malfunctions. Operators must also report injuries or illnesses of flight crew, in-flight fires, or structural failure of a turbine engine. NTSB must approve moving wreckage, contents, and records.

Railroads NTSB requires reports of all railroad incidents in which there is a fatality, injuries to five or more people, or more than $150,000 damage. The Federal Railroad Administration requires the same reporting. Railroads must also file a telephone report (with written follow-up) of any signal system failure. Each railroad must report and maintain a log of all incidents arising out of railroad operations. There are three incident classes:

1. rail-highway grade crossing cases
2. rail equipment cases
3. death, injury, or occupational illness.

Boats and Ships All vessels in U.S. waters and vessels owned in the United States and operated on the high seas must file casualty or incident reports with the U.S. Coast Guard. Reporting applies when a person dies or when there is an injury requiring medical treatment. It also applies if there are $200 in damages to a vessel or a vessel is lost in a boating incident. Operators must notify the U.S. Coast Guard immediately if a person dies or disappears from a vessel because of an incident.

Trucks When a trucking incident results in a death, medical treatment injury or $2000 property damage, a motor carrier must file a telephone report (and written follow-up) with the Motor Carrier Safety Office of the Federal Highway Administration. Motor carriers must also maintain a register of incidents. In addition, state traffic laws may require reporting of incidents other than those required by the federal government. Truckers must also maintain driving logs. They help ensure drivers take required breaks and limit continuous driving time.

Motor Vehicles There is no requirement for owners and drivers of motor vehicles to report incidents to the federal government. However, the FHWA strongly encourages state compliance with reporting standards to allow for compiling national statistics based on incident data.

Pipelines Carriers who transport liquids by pipeline must report incidents to the Pipeline and Hazardous Materials Safety Administration (PHMSA) within the Department of Transportation (DOT). They must report by telephone when there is

- an explosion or fire;
- a loss of 50 barrels or more;
- an evaporative loss of 5 gallons or more per day;
- a death;
- bodily harm resulting in loss of consciousness, medical treatment or disability;
- $1000 of property damage.

The operators of pipelines carrying natural and other gases must report leaks by telephone with written follow-up when leaks cause death or injury requiring hospitalization. They must also report when they remove a pipeline segment from service, gas is ignited or there are $5000 of property damage. PHMSA requires reports of smaller leaks and an annual report of leaks.

Hazardous Materials There is a requirement to report certain incidents in transporting hazardous material. An incident may involve loading, unloading, or temporary storage. A carrier must report immediately to PHMSA if the incident results in the death of a person, an injury requiring hospitalization, or certain other effects. The carrier must send a written follow-up report.

The Agency for Toxic Substances and Disease Registry (ATSDR) within the Department of Health and Human Services compiles data on toxic substances incidents during transport and at fixed facilities. The result is the National Toxic Substance Incidents Program (NTSIP). It produces an annual report of incidents, mainly involving chemical spills.

Defects and Noncompliance with Federal Standards

Manufacturers of products, those constructing or operating certain facilities and owners and users of certain equipment must maintain records of inspection and repair or design and testing. These regulations aim to ensure that facilities and products placed into use are safe. The regulations also aim to keep equipment and products that are in use in a safe condition. Owners or designers often maintain similar records. In some cases manufacturers require annual reports. In other cases, manufacturers must report defects or safety problems when they know about them.

Equipment in Use MSHA requires that companies keep records for inspection, testing and maintenance of person-hoisting equipment, shafts, boilers, compressed air equipment, ventilation equipment, emergency escapeways and facilities, fire doors, smokers' articles, hazardous conditions, methane, roof bolt torque, and electrical equipment.

OSHA requires that employers maintain records for the maintenance and inspection of equipment. Examples are powered platforms, cranes and derricks, fire extinguishers, forging machines, manlifts, presses, respirators, and safety valves for pressure vessels.

NRC requires that firms constructing, owning, operating, or supplying parts to regulated facilities report defects and noncompliance with regulations and licenses.

Railroads must maintain records of track inspections, operational tests, and inspections of equipment and tests involving the repair of signal equipment.

Cargo containers used in international shipping need periodic examination for safety. The U.S. Coast Guard requires records of such examinations.

Trucking firms must keep records of inspections, repairs, and maintenance of motor vehicles for the Federal Motor Carrier Safety Administration (FMCSA).

Aircraft owners must log maintenance, alterations, and rebuilding of aircraft, engines, propellers, and appliances.

Products and Facilities The U.S. Coast Guard certifies boats and associated equipment to ensure that manufacturers follow safety regulations and produce safe vessels.

Through a certification process the Federal Aviation Administration (FAA) ensures that aircraft, engines, propellers, and related products and parts are safe and airworthy. Manufacturers and owners participate in the certification process.

Every manufacturer of motor vehicles or items of equipment for motor vehicles must report defects related to motor vehicle safety and noncompliance with Federal Motor Vehicle Safety Standards (see Chapter 14). After the National Highway Traffic Safety Administration (NHTSA) receives notice of such safety problems, the manufacturer must implement a program to remedy the defects and report progress quarterly in the implementation of that program.

The Consumer Products Safety Commission (CPSC) requires that manufacturers, importers, distributors, and retailers report product defects that could create a substantial hazard. CPSC must report failure to follow its standards or bans of products.

For manufacturers of electronic products that emit radiation (ionizing or non-ionizing), the Food and Drug Administration (FDA) requires the reporting of information about such products. Included are data about their design, quality control and testing. Manufacturers must also maintain quality control and test records for those products, distribution data and sales data about purchasers. FDA requires reports of suspected accidental radiation occurrences, defects in products and failure to meet federal standards, together with plans to repair, repurchase, or replace such products. The FDA depends on voluntary reporting of ingredients in cosmetics and of unusual experiences with cosmetic products.

Several federal agencies have responsibility for compliance with facility safety standards by reviewing and approving designs. For example, FAA must approve the construction, modification, or abandonment of any airport. NRC closely monitors the planning, design, construction, and decommissioning of licensed nuclear facilities. The Federal Highway Administration uses an approval process for highways funded with federal money.

Hazardous Materials

Regulations of several federal agencies require records and reports about hazardous materials. For example, a manufacturer of explosives must report all sales of explosives to the Bureau of Alcohol, Tobacco and Fire Arms. The report must identify the quantity, date, and other data about each transaction.

Under the regulations issued by the Environmental Protection Agency (EPA) in response to the Resource Conservation and Recovery Act of 1976, a manifest system helps manage hazardous waste materials. Generators of hazardous (ignitable, corrosive, reactive, or toxic) waste must prepare manifests for all hazardous material they will dispose. The manifest moves with the material during transport, treatment, storage, or disposal. To track the materials, participants give copies of the manifest to state and/or federal EPA offices at each point in the disposal process. The Toxic Substances Control Act of 1976 requires manufacturers of potentially toxic substances to notify the EPA about such substances.

NRC similarly keeps track of all fissile material. Various organizations participate in creating or managing records of packaging, transport, transfer, and disposal of licensed material. In addition, NRC requires records of inspections and tests of materials, facilities for use, or storage, radiation monitoring and other equipment. There are also requirements for security records for the transport, storage, and use of fissile material. NRC requires reports of lost, unaccounted for, or stolen material.

Other Records and Reports

The federal government requires many other records and reports to assure the safety of workers and the public. FDA, for example, requires that manufacturers involved in the preparation, compounding, assembly or processing of medical devices for human use must register with the agency.

OSHA requires employers to keep records of workers' exposures to asbestos, ionizing radiation, noise and hazardous chemicals. Under "right-to-know" regulations employers must maintain information about the hazards of materials and substances. Workers with particular exposures (such as asbestos workers) must undergo periodic medical examinations. Employers must have records of safety training completed by employees.

MSHA requires that employers submit a training plan and records of training of miners about hazard recognition, emergency procedures, safety rules, and the use of safety and rescue equipment. Other regulations require records of exposure of miners to radon daughters, dusts, and noise and the submission of plans for mine ventilation, escape and evacuation, and roof control.

Organizations involved with fissile materials must keep records of exposure of workers to radiation and report data periodically to the NRC. Data must be available to workers.

Truck drivers must complete daily logs and submit them to their employers, who keep them under rules of the Federal Motor Carrier Safety Office.

Under provision of the National Highway Traffic Safety Administration, manufacturers of tires must maintain a list of first purchasers so they can notify customers of recalls. Similarly,

motor vehicle manufacturers must maintain a list of registered owners and must compile complaints, reports and other records concerning motor vehicle malfunctions.

This list goes on, not only for federal agencies, but also for state and local governments, insurance companies, and good safety management within individual companies. Record keeping and reporting are an essential part of safety activities.

8-3 THE OSHA METHOD OF INJURY AND ILLNESS RECORD KEEPING

Although there are many kinds of incident and injury record-keeping requirements and forms, the most commonly known system is that of the Occupational Safety and Health Administration (OSHA) and the Bureau of Labor Statistics (BLS). It provides a detailed example of incident record keeping. Details of the OSHA record-keeping requirements appear in 29 CFR 1904. They may change from time to time.

The OSHA system requires that employers keep an injury and illness log (OSHA Form 300). The employer must have the log available for OSHA inspectors. Employers must submit summary data annually on OSHA Form 300-A. An employer must keep the log for five years. OSHA also requires a supplemental record for each recordable case (OSHA Form 301 or equivalent).

Recordable Cases

Employers need not report every occupational injury and illness, only those that are "recordable." Recordable cases include:

- every occupational death;
- every occupational illness and injury involving:
  - days away from work;
  - restricted work; or
  - transfer to another job;
- medical treatment beyond first aid;
- loss of consciousness; or
- a significant injury or illness diagnosed by a physician or other licensed health care professional.

Other recordable cases include work-related cancer, chronic irreversible disease, a fracture or cracked bone, or a punctured eardrum. There are also needlestick injuries, cuts from a sharp object contaminated with another person's blood or potentially other infectious materials, tuberculosis infection after exposure to a known case of active tuberculosis, and musculoskeletal disorders (MSDs). Table 8-1 lists definitions for types of recordable cases. Figure 8-1 is a decision chart for deciding if a case is recordable.

Occupational Injury

An injury or illness is an abnormal condition or disorder. Examples of injuries are cuts, punctures, lacerations, abrasions, fractures, bruises, contusions, chipped tooth, amputations, animal or insect bites, electrocutions or a thermal, chemical, electrical, or radiation burn. Injuries include sprains and strains that result from a slip, trip, fall, or other similar accident.

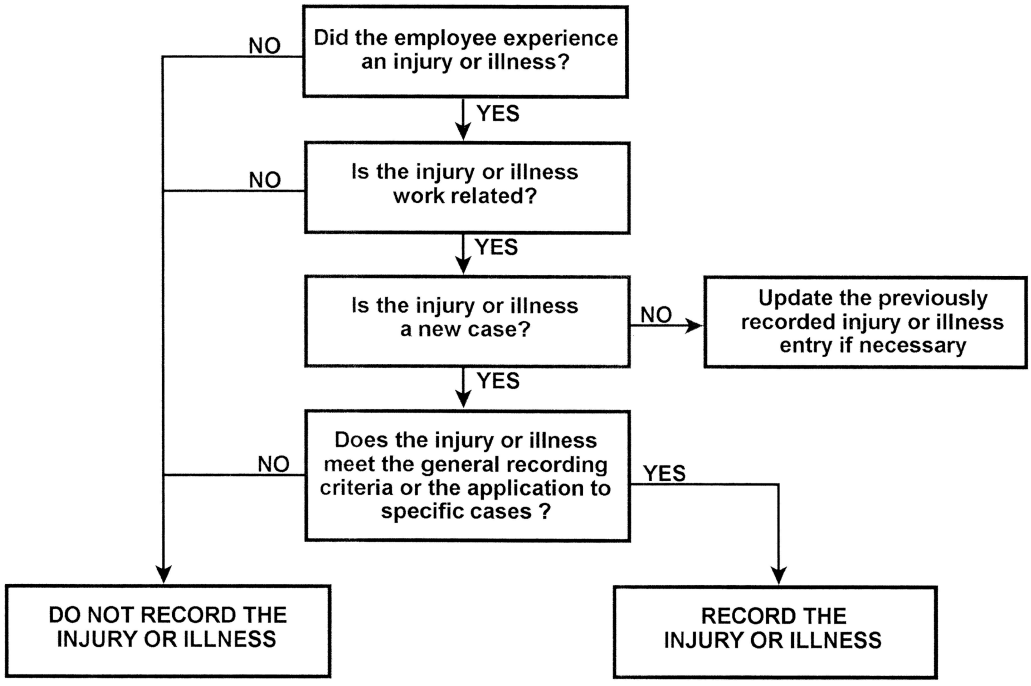


Figure 8-1. Decision chart for OSHA recordable cases.

TABLE 8-1 OSHA Definitions Affecting Recordable Cases

FIRST AID CASE

Incidents requiring *only* the following types of treatment are not recordable:

- using non-prescription medications at non-prescription strength
- administering tetanus immunization
- cleaning, flushing or soaking wounds on the skin surface
- using wound coverings, such as bandages, gauze pads, or butterfly bandages
- using hot or cold therapy
- using any totally non-rigid means of support, such as elastic bandages, wraps or back belts
- using temporary immobilization devised while transporting an accident victim
- drilling a fingernail or toenail to relieve pressure or draining liquid from blisters
- using eye patches
- using simple irrigation or a cotton swab to remove foreign bodies not embedded in or adhered to the eye
- using irrigation, tweezers, cotton swab or other simple means to remove splinters or foreign material from areas other than the eye
- using finger guards
- using massages
- drinking fluids to relieve heat stress

MEDICAL TREATMENT

Medical treatment is managing and caring for a patient for the purpose of combating disease or disorder, other than the following:

- visits to a doctor or health care professional solely for observation or counseling
- diagnostic procedures, including administering prescription medications that are used solely for diagnostic purposes
- any procedure that can be labeled first aid

RESTRICTED WORK

Restricted work activity occurs when, as the result of a work-related injury or illness, an employer or health care professional keeps, or recommends keeping, an employee from doing the routine functions of his or her job or from working the full workday that the employee would have been scheduled to work before the injury or illness occurred.

COUNTING RESTRICTED WORK ACTIVITY

Restricted work is the number of calendar days the employee had restricted work activity or was away from work as a result of the recordable injury or illness. The day of the injury or illness is not counted. Counting includes both the sum of the days away from work and the days of restricted work activity. Counting ends when either or both reach 180 days.

SKIN DISEASES OR DISORDERS

Skin diseases or disorders are illnesses involving the worker's skin that result from work exposure to chemicals, plants, or other substances. Examples are contact dermatitis, eczema, or rash caused by primary irritants and sensitizers or poisonous plants; oil acne; friction blisters; chrome ulcers; and inflammation of the skin.

RESPIRATORY CONDITIONS

Respiratory conditions are illnesses associated with breathing hazardous biological agents, chemicals, dust, gases, vapors, or fumes at work. Examples are silicosis, asbestosis, pneumonitis, pharyngitis, rhinitis or acute congestion; farmer's lung, beryllium disease, tuberculosis, occupational asthma, reactive airways dysfunction syndrome (RADS), chronic obstructive pulmonary disease (COPD), hypersensitivity pneumonitis, toxic inhalation injury, such as metal fume fever, chronic obstructive bronchitis, and other pneumoconioses.

POISONING

Poisoning includes disorders evidenced by abnormal concentrations of toxic substances in blood, other tissues, other bodily fluids, or the breath that result from the ingestion or absorption of toxic substances into the body. Examples are poisoning by lead, mercury, cadmium, arsenic or other metals; poisoning by carbon monoxide, hydrogen sulfide or other gases; poisoning by benzene, benzol, carbon tetrachloride or other organic solvents; poisoning by insecticide sprays such as parathion or lead arsenate; poisoning by other chemicals such as formaldehyde.

HEARING LOSS

For record keeping purposes noise-induced hearing loss is a change in hearing threshold relative to the baseline audiogram of an average of 10 dB or more in either ear at 2000, 3000 and 4000 hertz, and the employee's total hearing level is 25 decibels (dB) or more above audiometric zero (also averaged at 2000, 3000, and 4000 hertz) in the same ear(s).

ALL OTHER ILLNESSES

These include all other occupational illnesses. Examples are heatstroke, sunstroke, heat exhaustion, heat stress and other effects of environmental heat; freezing, frostbite and other effects of exposure to low temperatures; decompression sickness; effects of ionizing radiation (isotopes, x-rays, radium); effects of non-ionizing radiation (welding flash, ultraviolet rays, lasers); anthrax; bloodborne pathogenic diseases, such as AIDS, HIV, hepatitis B or hepatitis C; brucellosis; malignant or benign tumors; histoplasmosis, coccidioidomycosis.

MUSCULOSKELETAL DISORDERS

Musculoskeletal disorders are disorders of the muscles, nerves, tendons, ligaments, joints, cartilage and spinal discs not caused by slips, trips, falls, motor vehicle accidents or other similar accidents. Examples are carpal tunnel syndrome, rotator cuff syndrome, De Quervain's disease, trigger finger, tarsal tunnel syndrome, sciatica, epicondylitis, tendinitis, Raynaud's phenomenon, carpet layers' knee, herniated spinal disc, and low back pain.

Illnesses include both acute and chronic illnesses. Examples are a skin disease, a respiratory disorder, or poisoning.

Occupational Illness

Occupational illness may involve skin diseases or disorders caused by work exposure to chemicals, plants or other substances. They may be respiratory conditions associated with breathing hazardous biological agents, chemicals, dust, gases, vapors, or fumes at work. They may also be poisonings, noise-induced hearing loss, or other occupational illnesses.

Musculoskeletal Disorders

Musculoskeletal disorders are disorders of the muscles, nerves, tendons, ligaments, joints, cartilage and spinal discs that do not result from slips, trips, falls, motor vehicle accidents or other similar accidents. Examples include many disorders described in Chapter 13 and Table 8-1.

Case Classification

Not all work-related incidents are OSHA recordable. However, workers should report all cases to their employer. First aid cases are not recordable. Under the OSHA system, there are four classes of recordable cases:

- work-related death;
- any case resulting in days away from work;
- any case involving restricted job duties or a job transfer;
- other recordable cases.

Duration of a Case

In calculating the days away from work and restricted work days, OSHA counts calendar days. The total number of days includes weekend days, holidays, vacation days, or other days off if the employee did not work on those days. OSHA sets the maximum number of days for a case at 180 days.

Incident Rates

An incident rate is the number of recordable injury and illness cases occurring among a group of workers over the number of hours worked.

The OSHA injury and illness incident rate is:

$$\text{OSHA injury and illness incident rate} = \frac{\text{number of injuries and illnesses} \times 200,000}{\text{employee hours worked}} \quad (8\text{-}1)$$

The reference period represents 100 workers for a year (40 hours per week × 50 weeks per year = 200,000 hours). This number keeps the value that results from the formula small. The number of employee hours comes from company records. They represent hours actually worked. They do not include hours paid but not worked, such as vacation, sick, or holiday time.

Example 8-1 Assume the XYZ Machine Company had 192 employees who worked a total of 385,728 hours during a calendar year. The company experienced 10 recordable injuries and illnesses among employees. The incident rate would be:

$$\text{IR} = \frac{10 \times 200,000}{385,728} = 5.19$$

The Bureau of Labor Statistics computes and publishes incident rates for different industries and sizes of companies each year. The computations exclude death cases. Examples of industry composite incident rates for select NAICS[5] categories reported by the Bureau of Labor Statistics for 2013[6] are as follows:

Private industry	3.4
Agriculture, forestry, and fishing	5.5
Mining	2.1
Construction	3.7
Manufacturing	4.3
Trade, transportation, and utilities	3.9
Finance, insurance, and real estate	1.3
Service providing	3.2

OSHA and BLS also compute the incident rate for cases classified as death, cases resulting in days away from work and cases involving restricted job duties or a job transfer. This is the DART incident rate. The acronym derives from letters from the three categories.

$$\text{DART IR} = \frac{\text{Number of DART cases} \times 200,000}{\text{Number of hours worked}} \quad (8\text{-}2)$$

Severity Measure

A severity measure helps illustrate the impact of severe cases. The OSHA DART incident rate is one form of a severity measure.

The Bureau of Labor Statistics does some analysis based on the median number of days away from work for cases involving days away from work. One study showed the differences among age groups in median number of days away from work.[7]

Some use a severity statistic, often called the severity measure (SM). It looks at the days of lost work per injury and illness case.

$$\text{SM} = \frac{\text{sum of days} \times 200,000}{\text{hours of employee exposure}} \qquad (8\text{-}3)$$

The sum of days represents both days away from work and restricted work days.

Example 8-2 Suppose a mining company had several recordable cases that produced a total of 95 days away from work and restricted work. Some 389,295 hours were worked at the mine. The severity measure is then

$$\text{SM} = \frac{95 \times 200,000}{389,295} = 48.8$$

8-4 OTHER RECORD-KEEPING STANDARDS AND RECORDS

For a long time the American National Standards Institute (ANSI) has published record-keeping standards for measuring work injury and similar accident experience. The standards provided uniform record-keeping methods that employers and others used to assess the performance of safety programs. The National Safety Council (NSC) has published annual accident and incident statistics for a long time. NSC derived many of its records from ANSI record-keeping methods. When the Occupational Safety and Health Administration began in 1970, some of the methods changed to those of OSHA. The NSC annual publication was *Accident Facts* and now has the name *Injury Facts*. Now the publication includes the OSHA and BLS incident rates.

Another example is the standard on classification of motor vehicle traffic accidents published by NSC.[8] It provides a uniform method for compiling data on highway accidents. The Federal Highway Administration (FHWA) provides formulas for calculating roadway departure crashes[9] from crash rate data. The method helps highway planners select the types and locations for barriers and guardrails and implement other safety improvements.

For certain workers' compensation systems falling under state jurisdictions, the method for tracking and reporting injuries, illness and deaths may also differ from the above examples. Today, safety records may differ also by country and standards organization. One should investigate the current applicable standards that might apply.

EXERCISES

1. Obtain a copy of OSHA Form 300 and determine if the following cases should be logged on the form. If so, enter the appropriate data on the form. When logging days away from work or days of restricted work, assume that all workers work a five-day schedule (Monday through Friday) and have Christmas, New Year's Day, Memorial Day, Labor Day, Independence Day, and Thanksgiving Day as holidays. Use a calendar for the current year. If an injury date shown in a case falls on a weekend or holiday for the current year, move the injury date back to the last workday prior to the date in the problem. If a return-to-work date in a case falls on a weekend or holiday for the current year, move the date a person returns to work (restricted or full duties) forward to the next normal workday.

(a) John W. is employed in the press department as a press operator's assistant. On February 4, he cut his right hand on a sheet metal scrap. The company doctor treated him and gave him a tetanus shot because he had not had one recently. To avoid contaminating the wound with the grease used in the operation, he remained working in the department, but not at his regular job. He returned to his regular duties on February 18.

(b) Mary J. is employed in the packing department as a packer. On March 6, she dropped a carton on her foot, injuring the third toe on her left foot. The toe was so badly crushed that amputation of the entire toe was necessary. She returned on a full-time basis on May 7, but worked a job requiring less time on her feet. She returned to her regular job duties on May 17.

(c) Gary P. is employed as a paint sprayer in the paint department. On April 15 the exhaust system failed in the spray booth where he worked. He became ill after inhaling fumes, experiencing breathing difficulty and a headache. He stayed at home two workdays and then returned to work at his regular job.

(d) William O. works in the maintenance department as an electrician. While working on a high-voltage line supplying some heavy equipment, he was electrocuted, because he failed to lock out the power. The incident occurred on April 19.

(e) Sylvia P. is also employed in the maintenance department as a gardener for the summer. The week of June 29 was a scorcher. On June 30 she collapsed from heat exhaustion and did not return to work until July 10.

(f) Sylvia's sister, Sally P., also does gardening work during the summer. On July 18 she was stung by a hornet and developed a respiratory reaction that caused her to be out of work until July 24.

(g) Joseph C. works as a bookkeeper in the accounting department. On August 11 when he was checking some files, he turned around to return to his desk to answer the phone, tripped over an open file drawer and broke his right wrist. He returned to work on September 11, but could not operate the accounting computers (part of his regular duties) until the cast was removed on October 16.

(h) Jerry D. works as a press operator in the press department. On November 5 he received a cut on his left arm that required medical attention (10 stitches). He returned to his regular job in an hour.

(i) Marilyn G. works in the metal coatings department as a coatings specialist II. On October 5, while preparing some liquids used to finish products for a special order, she splattered some acid on both arms and received chemical burns to the skin. She remained off the job, receiving much special treatment, returning to her regular job on November 19.

(j) On May 12, Marvin K., a forklift driver in the shipping department was seriously injured when the vehicle he was driving tipped over on him. He suffered several fractures and some nerve damage in one leg that prevented him from returning to gainful employment. (For this exercise, compute this case to the end of the year only.)

(k) On September 22, Elmer F., a carpenter in the maintenance department, was helping stack lumber and ran a large splinter into his right hand. It was removed at the first aid station and treated. He returned directly to his job.

2. Compute the (OSHA) injury and illness incident rate for the company in Problem 1 for the year. Assume employees worked 123,413 hours during the year.

3. Obtain a copy of the workers' compensation standards used by a different state or country or published by a standards organization. Then evaluate each of the cases in Exercise 1 and determine whether the cases would fall under the record-keeping rules and how the recording keeping may differ from those applicable to OSHA Form 300.

4. For the company and cases in Exercise 1 and based on 2000 hours per employee year, what is the average time (work hours) between recordable incidents? Assume the company has 65 employees.

5. Locate a company whose records were inspected recently by an OSHA representative. Discuss experiences in trying to comply with OSHA record keeping with a company representative.

6. Locate a representative of a federal agency that requires safety record keeping and reporting. Have the representative discuss the effectiveness of their procedures and the value of such records for the agency in attempting to meet the laws and regulations that require such records and reports.

REVIEW QUESTIONS

1. List eight reasons why records and reports are important for safety.

2. Identify at least three federal agencies that require incident records and reports for employees.

3. For what kinds of transportation must incident records or reports be made?

4. Describe records or reports required for equipment in use.

5. Describe records or reports required for products and facilities.

6. Under the OSHA record-keeping requirements for injuries and illnesses, define the following:

(a) recordable case

(b) occupational injury

(c) occupational illness

(d) musculoskeletal disorder

(e) lost workdays

(f) days of restricted work

7. What is the OSHA injury and illness incident rate? For what is this statistic useful?

8. What is the DART incident rate?

9. What is a severity rate? What does this statistic measure?

NOTES

1 Mike Williamsen, "Near Miss Reporting: A Missing Link in Safety Culture," *Professional Safety*, 46–50, May 2013.

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4 10 CFR 20, Standards for Protection Against Radiation. Available at: www.nrc.gov/reading-rm/doc-collections/cfr/part020/

5 North American Industry Classification System. Available at: https://www.census.gov/eos/www/naics/

6 www.bls.gov/news.release/pdf/osh.pdf

7 www.bls.gov/opub/ted/2013/ted_20131230.htm

8 *Manual on Classification of Motor Vehicle Traffic Accidents*, 7th ed., ANSI D16.1, National Safety Council, Itasca, IL, 2007.

9 http://safety.fhwa.dot.gov/roadway_dept/

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Code of Federal Regulations. See applicable sections for record-keeping requirements of particular agencies.

SCHROTH, LORI, "Recordkeeping: Navigating OSHA's Requirements," *Professional Safety*, 28–34, August 2013.

PART III

HAZARDS AND THEIR CONTROL

THIS SECTION of the book, the largest, deals with hazards and their control. When seeking to achieve safety, a major role for engineers is prevention. Prevention requires that engineers recognize hazards, know available controls, and apply them. All too often engineers do not recognize hazards and factors that result in incidents. Sometimes situations involve complex combinations of factors that contribute to events. In many cases appropriate controls that are available to engineers are not applied at all or as fully as needed.

Sometimes engineers assume that when they apply their skills and knowledge to the best of their ability, then situations are safe enough. They assume that the products, equipment, workplaces, processes, and environments they design, implement, and manage are safe. They see themselves as professionals, people who know what they are doing. But incidents do happen, contributing factors are overlooked, errors are made, and things do go wrong. Too often engineers do not have the knowledge and skill to prevent such problems. They do not make things as safe as they could be, as safe as society expects, or as safe as the law requires.

The goal of this section is to develop the reader's general knowledge of hazard recognition and hazard control. Because of practical limits, this book cannot include every hazard or every control for each topic or application.

Hazard recognition, analysis, and control are the first and critical steps in a preventing undesired events. They are the cornerstone of safety management systems. Engineers and others involved in the prevention of harm play key roles in ensuring safe workplaces, products, equipment, and facilities.

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CHAPTER 9

GENERAL PRINCIPLES OF HAZARD CONTROL

9-1 INTRODUCTION

The aim of this chapter is to lay a foundation for discussion of many kinds of hazards and their control. The foundation involves understanding what a hazard is, how to recognize it and how to choose the controls that prevent incidents and accidents and any harm that may result. Other chapters in Part III of the book will apply this foundation to specific kinds of hazards.

Chapter 3 already introduced some aspects of this chapter's aim. It focused on accidents and accident causation theories. It gave some attention to prevention of accidents and introduced hazards and risks. Those elements will remain a focus in many chapters of this book. Chapter 3 also introduced some logical concepts for thinking about hazards, hazard recognition, and hazard control. This chapter will add additional concepts.

Before studying individual types of hazards and controls, it is important to have methods for anticipating and recognizing hazards and it is necessary to have methods for identifying and selecting controls that will be effective in the use environment.

9-2 HAZARDS AND HAZARD CONTROL DEFINED

Chapter 3 offered a definition for the term hazard. It is helpful to restate the definition:

A hazard is the potential or inherent characteristics of an activity, condition or circumstance which can produce adverse or harmful events and consequences.

Recall that a hazard may be an attribute of an activity, a condition, or a circumstance. The term hazard suggests there are causes for undesirable events. Risk is the likelihood of an adverse event and the potential severity that results from a hazard.

A hazard control is:

Any means of eliminating or reducing the risks resulting from a hazard.

Table 3-2 introduced the choices for controlling hazards and the preferred order for controls. Recall that those choices and their order are called the Hierarchy of Controls for hazards. Some also refer to Table 3-2 as the *Order of Precedence*. This chapter will explore the hazard control choices further.

To control hazards, one must be able to recognize them. A definition of hazard recognition is:

Perceiving or being aware that a hazard exists or could exist.

Hazard recognition involves anticipation. Recognizing a single hazard acting alone is not very difficult. However, in many situations, difficulty with recognition comes from the combination of activities, conditions, and circumstances that occur together. It is most difficult if a combination is not a usual one or when the three elements normally do not occur together.

9-3 SOURCES OF HAZARDS

There are many sources of hazards. People introduce some hazards. All too often, hazards arise from engineering activities, such as planning, design, production, operations, and maintenance. Seldom do engineers or others introduce hazards deliberately. Most likely they are the results of errors, oversight, or other inadvertent, unknowing or unintentional activities.

Many factors may contribute to the introduction of hazards: Pressure to meet design or production schedules, job stress, lack of or poor communications, and lack of knowledge may influence hazard recognition and control. Missing or incomplete instructions, untrained personnel, insufficient funds, uncommitted managers, and failure to

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CASE 9-1

As part of life, we all learn things do go wrong, stuff happens. Situations may be within our control our outside of our control. Bad experiences sometimes occur at the worst time.

An Air Force engineer, Captain Ed Murphy, had the same kinds of bad experiences in his job. He coined the phrase: "Whatever can possibly go wrong, will." His colleagues gave his expression the name, *MURPHY'S LAW*.

In the late 1940s, little was known about the forces a human body could withstand during deceleration. For years, Captain Murphy worked with Colonel John Stapp on deceleration using a rocket sled. Preparation for tests did not go well every time. This was the experience that triggered Murphy's Law.

Colonel Stapp, a career Air Force physician, used his own body for a lengthy series of tests over several years. His work led to a famous series of conferences on human physical tolerance and potential injuries from deceleration and automobile crashes. The conferences were called the Stapp Car Crash Conferences.[a]

With those events, Murphy's Law and many related corollaries became part of the English language.b The list below gives a few corollaries of Murphy's Law.[b,c]

Safety Engineering Corollaries of Murphy's Law

Hindsight is an exact science.
Only God can make a random selection.
When all else fails, read the instructions.
Any system which depends on human reliability is unreliable.
In any calculation, any error which can creep in will do so.
Any error in a calculation will be in the direction of most harm.
A fail-safe circuit will destroy others.
A failure will not appear until a unit has passed final inspection.
A car and truck approaching each other on a deserted road will meet at the narrow bridge.

[a] www.stapp.org/stapp.shtml

[b] A. Block, *Murphy's Law and Other Reasons Why Things Go Wrong*, Price/Stern/Sloan Publishers, Inc., Los Angeles, CA, 1977.

[c] A. Block, *Murphy's Law Book Two*, Price/Stern/Sloan Publishers, Inc., Los Angeles, CA, 1977, 1980.

seek assistance from safety, health and other specialists, all can contribute to hazards.

A poor safety culture and ineffective safety management system also contribute to hazardous conditions. Hazard analysis that limits its approach to technical flaws and individual failures will limit preventive actions to fixing technical problems and improved training of individuals. An underlying problem may involve organizational issues. Preventing catastrophic accidents and incidents, especially those involving complex situations, requires analysis of the culture and the safety management systems that allow the complex situations to develop. Chapter 35 covers this aspect in more detail.

Planning and Design

Planning is the process of setting goals and objectives. It involves defining actions and steps necessary to achieve them. It is formulating an orderly arrangement of parts. Designing is an extension of planning. It involves details and specific information for actions or for parts.

During planning and design activities, engineers and others may introduce hazards for sites, buildings, facilities, equipment, operations, and environments. A hazard may result from a computational error, failure to envision the use environment, making poor assumptions, selecting dangerous parts or features, or failing to envision how things will actually work.

There are many examples of planning and design errors. A few will suffice. A common computational problem for engineers is converting units of measure. For example, failure to convert square inches to square feet will produce a large error in a load calculation. Failure to include a factor of safety in a structural calculation can be disastrous. Using the wrong factor of safety can introduce a hazard.

Failure to envision the use environment can introduce hazards. For example, the force required by an operator to push or pull an object may be adequate when a floor is dry. The task may be hazardous when the floor is wet or shoes are muddy. The visibility of a display may be excellent for the designer, but obscured for an operator who is taller or shorter. An opening or access for servicing equipment may be large

enough for a bare arm, but inadequate when a mechanic wears heavy clothing in cold weather. A skylight on a roof may not be strong enough to stand on or its strength may diminish with continued exposure to sunlight. It becomes a dangerous stepping stool when placed adjacent to a roof-mounted refrigeration unit that must be serviced.

Making inadequate assumptions is another way hazards get introduced. Assuming that a load is static when it is really dynamic may result in failure. For example, football stands may not be capable of rhythmic loading as the crowd sways and stomps to the music of the band. Someone may make bad assumptions by failing to get accurate data from the literature, user testing, or specialists. One may assume that users will operate a product one way and not anticipate other uses. Designers may fail to envision some misuses.

Selection of materials can introduce hazards during design. A material may look attractive, but produce toxic substances if it catches fire. A material may have adequate strength, but have other properties, like creep or brittleness, that can lead to disaster. A material may quickly lose its strength when exposed to sunlight or moisture found in some use environments.

Failing to consider the life of a product during planning and design can introduce hazards. A product may be safe when new and become dangerous with use. Factors in a use environment can shorten product life. Examples are heat, chemicals, weather, vibration, freezing, wear, abrasion, or other adverse conditions.

Production and Distribution

Hazards can also result from production and distribution activities that engineers plan or manage. It is not always possible to construct or produce items the way they appear on design drawings. A specified fastener or connector may be unavailable. A substitute one may weaken a structural joint. Replacing one chemical with another may introduce toxic or flammable hazards. Poor packaging design may contribute to the introduction of hazards during handling and shipping. Inadequate packaging could result in a release of hazardous materials to handlers, distributors, or buyers.

Installation of products can introduce hazards. If installation instructions are incomplete and leave tasks to installer discretion, the product may become dangerous.

Maintenance and Repair

Designers often neglect setup, cleaning, regular maintenance, and repair activities. They focus on normal use and operations. However, setup, cleaning, maintenance and repair activities often are more dangerous than normal operations. These activities frequently introduce hazards not present during normal use.

For example, poor access to service points may make cleaning and maintenance dangerous. Normal operating speeds may create dangers during cleaning and service. Designers need to anticipate hazards during or resulting from maintenance, repair or cleaning, not just normal operation or use. Designers need to develop procedures and instructions for proper installation and setup and for maintenance and repair.

Failure to provide manual power or inching controls for powered equipment may make service and setup activities dangerous. Failure to tighten a bolt or tightening it too much may create a hazard. Proper torque may be critical. Failure to lock out or provide lockout capabilities for electrical, steam, mechanical power, spring or hydraulic pressure or fuel sources during maintenance creates hazards. Failure to lock or block parts from falling can lead to injury. Failure to clean up work areas before, during, or after servicing and repair can introduce hazards. Errors in maintenance procedures or poorly written procedures can cause hazards. Failure to barricade areas undergoing maintenance activities may allow unqualified or unaware individuals into dangerous areas.

CASE 9-2

Seating prepared for a fast food shop required proper installation to prevent tipping over when occupied. The installation instructions identified where fasteners connected the seating units to a wall. The installation instructions showed where screws passed through anchoring holes on the seating units and specified the screw size number, but not the number of screws or their length. The instructions did not discuss what wall conditions, anchoring schemes, and fasteners would assure proper anchoring strength.

For example, if attached to a wall finished with drywall or plasterboard, screws had to connect to structural elements behind the drywall, such as wood studs. They needed to extend at least 2 inches into wood studs. Other kinds of walls and studs needed different attachment schemes.

One installer ran screws to drywall material alone. That left the seating unit unable to hold the weight of an adult patron. A patron sat down on a unit. The unit tipped over as the screws ripped from the wall. The fall injured the patron. A legal challenge identified the failure of the seating manufacturer to provide precise instructions for installation that would make the seating units stable and safe. Actual installation was at the installer's discretion. He did not understand structural and stability implications.

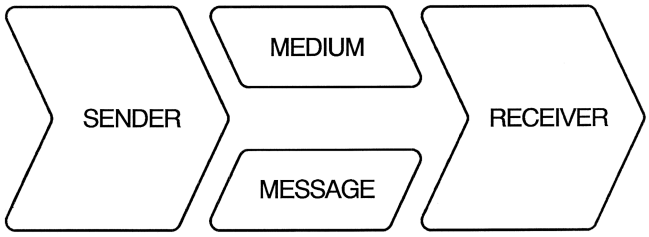


Figure 9-1. The four components of communication.

Communication

Poorly executed communications or failure to communicate can introduce hazards. Changes in design of equipment, procedures, and operations can introduce hazards. This is especially true when a design change introduces new hazards. Failure to communicate the changes and their consequences adds to the problem. Communication methods and the knowledge and understanding of receivers are important. Instructions and user manuals must convey information effectively from designer to users. A common writing error is explaining how something works as an instruction. Both explanations and instructions may be helpful. Instructions are a sequence of actions to take, not descriptions. Poor communication leads to errors, incidents, and losses.

The four components of communication are essential in safety engineering. The four components are sender, receiver, media, and message (see Figure 9-1).

Designers, safety engineers and other specialists have important roles in communications. They need to communicate designs, specifications, and procedures involving safe operations, use, maintenance, setup, and cleaning. Designers should even participate in preparation of advertising materials. Hazards and controls are important parts of advertising in a society filled with legal claims.

Organizational Factors

There are many kinds of organizational factors that contribute to hazards. They may involve lack of effective safety management systems (see Chapters 3 and 35). They may involve a low priority for safety among work group leaders or among company executives. Lack of planning, incomplete organization of work, poor organization of materials and work flow, and inadequate training and instruction for safe work may all contribute to hazards. Some organizations do not communicate well within work groups to ensure safe work or between work groups to alert others of job hazards. Overall, the work climate may fail to create a safety culture. Case 9-3 offers an example of organizational factors that led to catastrophic failures.

9-4 PRINCIPLES OF HAZARD CONTROL

In order to minimize hazards, one must be able to do the following:

1. Recognize them.
2. Define, select and plan for preventive actions.
3. Assign responsibility for implementing preventive actions.
4. Provide a means for measuring the effectiveness of controls put into place.

CASE 9-3

On March 23, 2005, explosions and fires at the BP Texas City Refinery killed 15 people and injured 180 others. Financial losses totaled more than $1.5 billion. Officials ordered 43,000 people nearby to remain indoors.

During a startup procedure, there was a series of operational errors that led to the explosion and fire. Following the incident, OSHA identified 301 willful violations and served a $21 million fine on BP.

The Chemical Safety Board (CSB) investigation report[a] identified seven significant facility and operational factors that had contributed to the incident. One of those was siting support trailers for workers too close to the highly hazardous process unit. All fatalities occurred in and around the trailers.

The CSB report claimed that OSHA inspections failed to focus on compliance with process safety standards. The report also identified nine organizational factors for BP that contributed to the incident. Among the factors was "Safety campaigns, goals, and rewards focused on improving personal safety metrics and worker behaviors rather than on process safety and management safety systems."

An urgent recommendation to the BP Group Executive Board of Directors was to "convene an independent panel of experts to examine BP's corporate safety management systems, safety culture, and oversight of the North American refineries." BP accepted the recommendation and implemented a special safety review panel.

[a]www.csb.gov/assets/1/19/CSBFinalReportBP.pdf

TABLE 9-1 Most Frequently Cited OSHA Violations in 2013

2013 Rank	Standard	Topic	Total 2013 Violations	Rank in Previous Years		
				2012	2011	2010
1	1926.501	Fall Protection	8,241	1	1	2
2	1910.1200	Hazard Communication	6.156	2	3	3
3	1926.451	Scaffolding	5,423	3	2	1
4	1910.134	Respiratory Protection	3,879	4	4	4
5	1910.305	Electrical, Wiring Methods	3.452	8	6	7
6	1910.178	Powered Industrial Trucks	3.340	7	7	8
7	1926.1053	Ladders	3,311	5	8	5
8	1910.147	Lockout/Tagout	3,254	9	5	6
9	1910.303	Electrical, General Requirements	2,745	10	9	9
10	1910.212	Machine Guarding	2,701	6	10	10

Source: www.osha.gov/Top_Ten_Standards.html, www.nsc.org/Pages/OSHA%E2%80%99s-Top-10-Violations-for-2013-announced-at-National-Safety-Council-Congress--Expo.aspx, and other sources.

Together these four steps can achieve hazard control. A number of methods are available to accomplish these steps systematically. Part V of this book details several methods.

Knowledge and Recognition of Hazards

As noted earlier, no one individual can be fully knowledgeable about all hazards. Several disciplines and specialists may need to work together. Input and experience of workers can help.

Safety engineering requires a knowledge of hazards in many different topics. Safety engineering also requires a broad knowledge of engineering and systems. In contrast, many engineering disciplines provide in-depth knowledge of particular topics. Thus, the specialty of safety engineering requires knowledge of hazards and potential controls across many engineering disciplines.

After one has developed a knowledge of hazards, there is a need to develop skill in recognizing and understanding hazards. Sometimes one must anticipate hazards by knowing that bringing certain materials, activities or conditions together produces hazards which otherwise are not present. One must consider the use environment and many different contexts. Only after hazards are recognized can one identify and select suitable controls. Case 9-2 illustrates how knowledge of the use environment is critical to a safe product. Details in the report on Case 9-3 illustrate how a range of errors and lack of design details led to a catastrophic failure. This case also shows how focusing only on individual hazards does not provide the overall hazard picture for complex systems and operations.

Historical data often helps in identifying or anticipating hazards that may exist or potentially exist. For example, OSHA publishes annual statistics based on the frequency of citations for OSHA standards. Table 9-1 provides example data for 2013 and previous years. The rate of citations may help identify hazards to look for and resolve. It is worth noting that the rank and number of citations by OSHA include the same categories year after year. In addition, writings in the early 1900s focused heavily on machine guarding.[1] Yet machine hazards continue as problems today.

Internal company data from workers' compensation claims, OSHA or other logs of incidents, or company accident reports can help identify hazards that require attention.

Priorities

There is an internationally accepted set of priorities for selecting hazard controls. Some refer to this list as "design order of precedence." The list appeared in Table 3-2.

Once again, the priorities, in order of importance, are:

- Eliminate the hazard.
- Reduce the hazard level.
- Provide safety devices.
- Provide warnings.
- Provide safety procedures (and protective equipment).

One must consider many factors when selecting and implementing controls for hazards. Risk, cost, type and severity of loss, practicality and not introducing additional hazards are all important. For type of loss, the first priority is to protect people and prevent loss of human life. Protection of property, environments, and operations follows. Haddon's energy release theory and other schemes and models (see Chapter 3) provide ideas for dealing with these priorities. Some additional models that help recognize hazards and plan for controls occur later in this chapter.

Eliminate the Hazard

The highest priority in hazard control is to eliminate or avoid the hazard. Once eliminated, the potential for harm or loss is

CASE 9-4

In March 2014, General Motors recalled 1.6 million automobiles. The repairs by dealers took a few minutes for each auto and cost GM about $8 million.

The problem involved ignition switches. Drivers turned the ignition key from "off" through the "accessory" position to "on." The detent plunger and spring inside it allowed the ignition switch to turn back to the "accessory" position when someone bumped the key or there was too much weight hanging from the key's head. That disabled the car's airbags. GM linked the problem to accidents that had resulted in 12 deaths. The repair involved replacing the detent plunger with one containing a stronger spring.

The recalled automobiles were manufactured between 2003 and 2007. GM became aware of the defect as early as 2004. The fact that GM did not issue the recall until 2014 raised questions from government officials.

gone. Process or design changes or substituting a nonhazardous material for a hazardous one will eliminate hazards. For example, elimination of manual handling steps in an operation will eliminate lifting hazards. A noncombustible material can replace a combustible one. Operations can remove sharp corners by rounding them or filing them to remove cutting potential. One can remove wastes that are fire hazards or can become falling objects.

Reduce the Hazard

If one cannot remove a hazard, the degree of hazard can often be reduced. Two approaches are reducing the degree of severity or reducing the probability of occurrence.

Reductions in degree of severity lead to less injury, illness, or damage. For example, moving a fire hazard to where it is distant from people is a reduction in degree of severity. Fewer people have a chance of being injured. Placing hazards where there are few people reduces hazard severity. Using smaller quantities of flammable or toxic material or reducing energy levels at an occupied location is also a severity reduction. Sprinkler systems do not prevent fires. They simply minimize their severity.

Reducing the probability of occurrence means that a hazard is less likely to create an incident. One means to accomplish this is to use parts that have a longer life and do not fail as often. Designing for lower failure rates, using redundancy and avoiding single point failures are others.

Redundancy Redundancy can reduce the probability of error or failure in an operation or system. Redundancy means providing more than one means to accomplish something, where each means is independent of the other.

Parallel Subsystems and Components There are several kinds of redundancy and ways to implement redundancy. One is to provide two or more parallel subsystems or components. For example, Figure 9-2(a) illustrates a circuit that will not operate if the single actuating switch remains open or fails in an open position. The circuit in Figure 9-2(b) will operate if someone closes either switch A or switch B or closes both. Leaving either switch open will not disable the energy for the circuit.

Backup Systems Another way to provide redundancy is using a backup system. For example, on some aircraft, the aileron control is activated by hydraulic devices. Some aircraft have as many as four separate hydraulic systems to minimize the chances of control failure. Failure in one system will activate a second system. The second is not normally in operation until the first one fails. For example, having candles or lanterns available for use when the electricity goes off and lights are out is a form of backup system.

Partial Redundancy In some systems there is partial redundancy. Suppose there is only one pump supplying two sets of hydraulic lines to an actuating cylinder. The pump and cylinder have no redundancy, whereas the lines do.

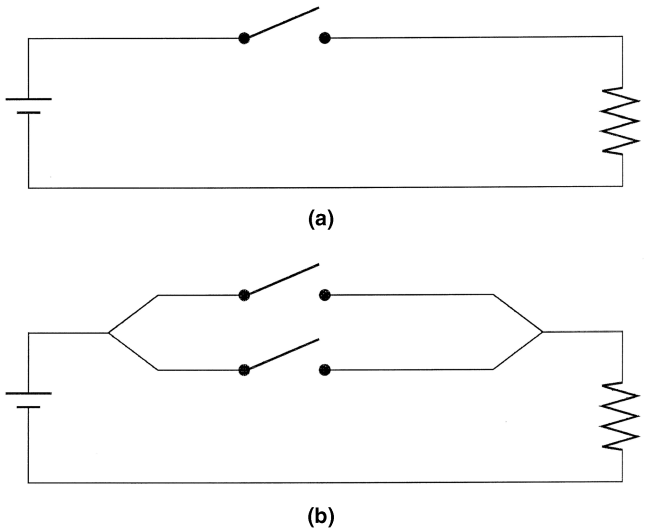


Figure 9-2. Circuit (a) has no redundancy in the switch that activates the circuit, whereas circuit (b) does have redundancy with two independent switches that can close the circuit.

The system has only partial redundancy. A failure in the pump or cylinder would produce a failure of the system. A blockage failure in one of the lines would protect the system from failure because there is a second line. However, routing the hydraulic lines through the same locations reduces the value of the redundant lines. Damage to one is likely to occur to the second. The value of redundancy increases if there are different locations for the redundant components

Human Operators and Automatic Equipment Redundancy can involve both human operators and automatic equipment. The cruise control on an automobile is an automatic device that keeps a car moving at a steady speed. The driver can also control the speed of the car by depressing the accelerator pedal. The driver and the speed control are redundant. The driver can fully override the speed control by disengaging it with a switch on the brake pedal or pressing a dashboard or steering wheel switch to deactivate it.

Multiple Operators Use of more than one person can provide redundancy. In aircraft, a pilot and a copilot can perform the same function. If one is incapacitated, the other can take over (parallel redundancy). Another example (series redundancy) might be a two-person press. Both operators may face the hazard of getting caught in the machine when it is in motion. If each operator has a two-hand control, all four hands of the operators must depress the switches before the machine will operate.

Another example is the use of two people for cleaning or repairing a closed container. First the team will check the container for hazards and take appropriate protective actions. For example, there will be personal protective equipment, recovery harnesses, fire extinguishers, or other equipment. Only one person enters the enclosure. The other watches and provides help in case the first encounters some difficulty. The second person does not enter the enclosure without a replacement, third person, at the backup position.

Single Point Failure A single point failure is a failure of a component or subsystem that results in failure of the entire system. A broken starter switch or a dead battery in a car renders it inoperable. They are single point failures. Designers should avoid single point failures particularly if a failure of the system can produce dangerous conditions.

Safety Devices

Safety devices can reduce hazards in many cases but not eliminate them. Safety devices are features or controls that prevent people from being exposed to a hazard that exists. Once a safety device is in place, operating correctly, and properly maintained, it requires no action on the part of people. Safety devices are automatic devices. One must remember that safety devices do not remove a hazard. A major difficulty with safety devices is that they are often removed or rendered inoperative, exposing someone to a hazard.

Machine guards are examples of safety devices. They prevent operators from getting into a hazardous area of a machine. Fences, interlocks, shielding, and enclosures are all forms of safety devices.

Fail-Safe Devices Fail-safe devices are safety devices designed to prevent exposure to hazards. They also prevent injury or damage when a system or machine fails. Examples of fail-safe devices are automatic fire doors, air brakes on truck trailers, a dead-man switch on powered hand tools, and safety cans with a spring-closing lid for flammable liquids.

Fail-safe devices may be *fail-passive*, *fail-active*, or *fail-operational*. A fail-passive device, such as electrical circuit breakers or fuses, will render a system inoperative or de-energized until corrective action is taken. A fail-active device will keep a system energized but in a safe mode until there are corrective actions. A fail-operational device allows a system to function safely, even when the device fails.

Fail-Dangerous Devices Devices that fail and leave dangerous conditions in place or expose dangers are fail-dangerous devices. Some designers may create features for safety devices without considering what effects will occur upon failure. There is a good chance such devices will be fail-dangerous.

CASE 9-5

January 28, 2015, New Zealand. During an investigation of an incident involving Flight NZ57 on October 11, 2014, investigators learned new information that meant the safety of passengers and crew was compromised. The Air New Zealand flight was leaving Fiji for Auckland, NZ, when the ground service workers advised local airline personnel that the scale weighing freight had broken down. The local airline authorities decided to rely on shipping documents to establish the weight of the cargo.

Fortunately, the shipping documents were correct. The airline policy required the cargo to be weighed independently before loading an aircraft. The policy required a form of redundancy to ensure aircraft safety. The weight and distribution of loads on aircraft are critical to their ability to fly safely.[a]

[a]http://tvnz.co.nz/national-news/air-nz-breached-safety-procedures-not-weighing-cargo-6222607

CASE 9-6

Packaging can become a fail-safe device.

Consider the case of a connector for a gas valve that the manufacturer includes with the valve. When in place, the connector joins two screws that are part of the pilot light circuit. A thermocouple heated by the pilot light creates a current to operate the protective circuit.

A typical gas valve has four screws on it. The first and second connect to a temperature limit switch, a safety device, that interrupts the circuit and shuts off the gas flow if the temperature at the switch sensor gets too hot. The second and third screws may connect to a second temperature limit switch or other safety device. If there is no second safety device, there is a small jumper or connector that links the second and third screws to continue the circuit. The third and fourth screws connect to the thermocouple that creates the current for the circuit.

A manufacturer normally shipped the gas valves with the small jumper in place on the second and third screws. The assumption was that most installations did not have a second safety device. Installers had to connect the first and second screws to a temperature limit switch. They also had to connect the third and fourth screws to the thermocouple.

A home owner installed a replacement gas valve on a floor furnace. It has two temperature limit switches. He connected the first temperature limit switch to the first and second screws and the second temperature limit switch to the second and third screws. He did not remove the connector already in place. He connected the third and fourth screws to the thermocouple.

Later, the floor furnace overheated the second temperature limit switch. Because the connector was in place, the switch did not turn off the gas valve. The high temperature caused a fire that burned an occupant in over 65% of the body.

The case ended in a products liability lawsuit against the gas valve manufacturer. Had the manufacturer placed the connector in a small plastic bag and shipped it uninstalled, the connector would have changed from a fail-dangerous device to a fail-safe device. The gas valve would not have worked at all if someone failed to install it when there was no second safety device. It would have worked properly if either the connector or a second safety device were installed. Warnings with the connector would have prevented connecting both during installation of the gas valve.

Warning Devices

Another way to reduce hazards is to warn people. Warnings notify people of a hazard or danger. Warnings do not remove a hazard. They do not prevent access to a hazard or render a hazardous condition safe. Warnings depend on people to take some action that will prevent them from being exposed to or injured by a hazard. Warnings depend on human action to implement protection. They are effective only when humans perceive them, understand them, and act correctly in response to them. Warning devices often rely on sensors to establish that a hazard exists and issue a warning.

Most warnings signal people through visual or auditory senses. Some common examples are signs, symbols and visual or auditory alarms. Warnings may involve flags, labels, signs, flashing or changing lights, sirens, whistles, horns, and other means to notify people that a hazard exists. With today's electronic systems, warnings may have voice statements and instructions. Warnings can fail or be ineffective because of complexities involved in their use. Because communication is a complex process, select and use warnings with care.

Effective warnings typically include the elements listed in Table 9-2.

A warning is useless if any of the steps in Table 9-2 fail. In addition, a warning itself must meet many criteria. Table 7-1 identified 15 characteristics that warnings should have.

Warnings that seem similar can result in the incorrect action because people confuse the proper actions. For example, a fire horn in a school has a long continuous sound. On the same system a tornado warning has a sound that alternates between high and low pitch. The appropriate actions in each case are opposite of each other. For a fire, children must exit the building. For a tornado, they are to get down along the wall in a central corridor. An error in action can be deadly. At

TABLE 9-2 Elements of an Effective Warning

1. Designers must recognize hazards during design or incorporate sensors to detect a hazard.
2. The hazard design or sensor must differentiate the hazard from other hazards.
3. The designer must create a warning to be presented or actuated.
4. The warning must be in place or operate.
5. A receiving person must sense (see, hear, feel) the warning.
6. A receiving person must perceive the information as a warning relative to the background.
7. A receiving person must understand the warning's meaning.
8. A receiving person must know what protective action(s) to take in response to the warning.
9. A receiving person must take the appropriate protective action(s).
10. A receiving person must complete the action(s) in a timely manner.

least one Midwest grade school completed the wrong action. The children exited when there was actually a tornado.

Several warnings at the same time can confuse people. Similar warnings occurring close together can also create confusion. When there are several warnings at or about the same time, people get confused, particularly if competing warnings have different priorities. People will forget which warning to follow first.

During the major loss of coolant incident at the Three Mile Island nuclear power plant, 500 or more audio and visual warnings went off during the first minute of the incident sequence. Over 800 warnings occurred by the end of the second minute.[2] Operators had sensory overload. They had trouble deciding which warning to act on first. The confusion contributed to the overall severity of the incident.

Procedures

Procedures can help reduce the danger from hazards. Procedures are sets of actions that people must execute. People must learn to use safe procedures. Designers and safety professionals must develop effective procedures. Users must understand them before applying them. Procedures must be safe and accomplish the desired goal in an efficient manner. One can establish procedures for efficiency, management control, and many other purposes beside safety. There are a number of methods (see Part V) available for analyzing procedures to determine whether they are safe, sufficient, and effective.

One needs to design procedures to minimize danger to anyone using them. Procedures should not introduce unsafe practices and should not put someone in danger. People must be taught and develop skills in following safe procedures. People should learn why safe procedures exist and what hazards the procedures attempt to help them avoid.

People need to recognize hazards that may occur during the use of procedures and how to act if such contingencies occur. For example, people are often taught how to operate a machine. Then they start to use the machine and something unexpected occurs that their training did not include. Because the procedures did not cover such an event, the operator must use individual judgment to take the correct action. Too often the wrong action is taken. Because new and inexperienced operators are not familiar with the unexpected and how to protect themselves, the incident and injury rate for new employees is very high. Often new employees are not taught how to deal with non-routine conditions.

Procedures are the lowest and least preferred hazard control in Table 3-2. The reason is they depend totally on human behavior to recognize the hazard as it occurs and take appropriate corrective action. The hazard may be present at all times. It may appear all of a sudden. A person must recognize the hazard, know there is a need for a procedure, know what procedure to apply, recall the procedure details and execute it correctly.

Applying procedures can be complex. A person must differentiate the dangerous situation and procedure from all other similar ones. A person must apply skill to complete the procedure. It may be necessary to practice the procedure often to retain the proper skill level. A person must have the physical capabilities to perform the procedure. All actions must occur in a timely manner. Failure in any one of these steps can result in inadequate protection.

Personal Protective Equipment

Some hazards that remain require use of personal protective equipment. Personal protective equipment is part of a procedure. Wearing special equipment depends on human behavior and requires user cooperation. Someone must select personal protective equipment that protects against the hazard present. It must fit properly. It must be in good condition. It must be clean. It must not create additional hazards. Users must wear it, because the hazard remains.

Chapter 28 covers personal protective equipment in detail.

9-5 ENVIRONMENTAL HAZARDS

When dealing with hazards of environments, there are additional important factors. Environments include such things as heat, light, noise, vibration, pressure, chemicals, and radiation (non-ionizing and ionizing). Designers must know what level of exposure exists or could exist. One must consider the exposure's effects on people. There is a need to know how exposures occur. There is a need to detect and measure the exposures. People cannot observe many environmental hazards or assess them accurately on their own.

Two kinds of information reveal if there are environmental hazards. In most cases exposures require measurements with suitable instruments. In addition, there is a need for reference standards. Reference standards state what level of exposure is dangerous. Effective procedures determine if a hazard exists.

To deal with environmental hazards, those involved in providing hazard controls need to know how human bodies respond to the hazardous conditions. They need to know what controls will eliminate or reduce the hazards.

Effects

Exposures to hazardous environments produce few traumatic injuries. Most often there are health effects. Some exposures produce non-traumatic injuries or have cumulative effects.

There can be some traumatic injuries. Thermal environments can cause burns. Exposure to extremely loud noise

can injure the eardrum. Exposure to high intensity ultraviolet radiation can injure receptor cells in the eye.

More often, environmental exposures lead to health disorders. Exposures to hot environments can produce various illnesses and physiological disorders. Exposures to noise can produce forms of stress and lower tolerance for others. Long-term exposure to noise causes hearing loss. Exposure to high levels of ionizing radiation can result in acute illness and death, and exposure to low levels may lead to delayed illnesses, such as cancer.

Some environmental exposures have delayed effects. Illnesses may not appear following exposures for hours, days or even years. The time between exposure and onset of symptoms is the *latency period*. Some cancers associated with exposures to certain materials and environmental conditions may not appear for years. A more extreme latency period is on the order of 30–40 years.

Some effects of environmental exposures appear as behavioral effects. Exposure may change how someone behaves. Some behavioral changes are easy to recognize. For example, consider the parents who are irritated by the constant blare of their teenager's stereo. They may feel tense and yell at their child as a result. Some chemicals affect nerve transmission or muscle action. A person exposed to such materials may exhibit noticeable reduction in motor skills. Other materials can cause loss of memory that affects a person's job skills. Often those around an individual will not associate these behavioral changes with some environmental exposure. The symptoms can result from many other causes as well.

Sometimes a professional starts to treat a behavior problem, but not the real cause. An example is "mad hatter's disease" or "Danbury shakes." Employees in the hat-making industry around Danbury, Connecticut, were exposed to mercury and became nervous and irritable and exhibited shaking. Family or physicians did not recognize the relationship between the behaviors and exposure to mercury.

There are significant differences among people in their physical, emotional, and behavioral response to environmental exposures. For example, some people burn easily in sunlight; others do not. Some people will get a skin rash from contact with certain solvents, while others will not for the same exposure.

People become sensitized in some cases. For a long time they do not exhibit any effect when exposed to an environmental agent, then they do. After the first response occurs, further exposures at even low levels will initiate the response.

Information Requirements

Exposures to environmental conditions and substances do not always produce effects. Not all exposures are harmful and some can be beneficial. For example, exposure to sunlight provides a means of acquiring vitamin D but excessive exposure can lead to burns, and long-term exposures can cause skin cancer.

Several information items are necessary to determine if an environmental condition is hazardous. Designers will have to make estimates and for actual exposures one must make measurements. The first item of information is knowing the agent. It is easy to distinguish thermal conditions from noise. It is not as easy to tell which chemicals are present in the air. It may be difficult to identify an agent's form, since some may be airborne solids, gases, or vapors. For ionizing radiation, one must know the kind of radiation present and often the wavelengths present.

The second item of information the quantity or concentration of an agent. Measurements vary for different agents. For thermal environments, for example, there is a need to measure the dry bulb air temperature, humidity, air velocity, and radiant heat load. For non-ionizing radiation, one must know the intensity and wavelengths. For airborne chemicals, one must know the concentration of each contaminant present.

The third item of information is the duration of exposure. The level of hazard for many environmental agents is a function of the dose. A dose means both the duration of exposure and the concentration of an agent during the exposure period.

Hazard Determination

From the three items of information it is possible to find out if an exposure is hazardous. For some agents it is necessary to complete a computation to determine the hazard for an exposure. To determine if there is a hazard, it is necessary to compare the actual exposure to a reference standard. Reference standards come from studies of illnesses and related exposures. In some cases scientific specialists recommend allowable exposures. In other cases, government agencies set exposure limits. Not all reference standards agree on allowable exposures and exposure limits. Over time, additional studies may lower recommended exposures. Government agencies in different countries will not agree on allowable exposures. The philosophies that influence reference standards may differ.

In general, the reference standards identify which exposures are allowed or what knowledgeable people recommend. Decisions on actual exposures will want to consider multiple sources of reference standards and understand how they come about and when they were set.

Instrumentation and Measurement

Special instruments help determine the agents present in an environment, their form, and their intensity. There are at least two classes of instruments: laboratory instruments and field instruments. Laboratory instruments are not portable and may require special support systems. Operators need training to use the laboratory instruments correctly and gain accurate results.

Field instruments are portable, but may be less accurate than laboratory instruments and most require limited training.

In some cases, it is easy to capture environmental samples without contaminating them. Specialists who know proper procedures capture the samples and bring them or send them to laboratories for analysis. Many of these procedures involve some time lag before exposure information is available.

With the rapid computerization and miniaturization of instruments of all kinds, it may be possible to make precise measurements in the field with little training. In many cases the field instruments give direct readings that allow immediate decisions. There are also many miniature sampling devices that gather samples for analysis in a laboratory. There are sampling devices that simply are pinned to workers' clothing to track their exposure during a work day or other time period.

Portable instruments acquire field measurement. Some can transmit data to a central location for immediate analysis. Measurement systems provide data collection points that feed to a central location for continuous monitoring of conditions. The instruments can transfer data over the internet to a central location for analysis and quick results.

For each kind of chemical and physical exposure, there are accepted procedures and instruments for making measurements. This book cannot provide full details on current instruments and measurement procedures. Readers should refer to current publications and regulations about accepted practices. Readers can also seek assistance from occupational safety and health or industrial hygiene professionals.

Health Standards

Reference standards for environmental agents (physical and chemical) have frequent updates. The updates incorporate new knowledge and add new agents, as there is limited knowledge about exposures to a new agent, the effects of exposures, and the mechanisms that link exposures to illness or injury. Most reference standards result from research studies, testing, and incidental exposures. Testing can involve either animal or other studies. Occasionally, human volunteers participating in studies provide direct information on the effects of environmental agents on humans. For incidental exposures, data is limited, since measurements were not made or systematically collected. Reference standards result from current knowledge. New information is most likely to make reference standards more restrictive to improve safety.

The main sources of government environmental standards are OSHA and EPA. OSHA sets workplace standards.[3] NIOSH makes recommendations on exposure limits and compiles related helpful information.[4] EPA sets standards for air and water quality for the general public.[5] Other agencies, like CPSC and FDA, also set reference standards related to certain products. For work environments, the American Conference of Governmental Industrial Hygienists publishes recommended standards of exposure for chemical and physical agents.[6] An internet search will help locate reference standards for other countries.

9-6 HAZARD CONTROL MODELS

The complex relationships among people, machines, environments, and organizations can make hazard anticipation, identification, and control difficult. Using only one method to identify and control hazards may be insufficient. Chapter 3 introduced some hazard theories and ways to think in an organized way about hazards and their control. This section offers additional thinking models. One should view hazard management from several different thinking models.

Consider the problem of protecting people from falling into an excavation. A construction contractor may place barricades around a trench or hole. That may not be effective at night. The contractor may add flashing lights on the barricades for visibility. For blind people. the flashing light is useless. The contractor may use flashing units with beepers to include an auditory warning. Children may ignore the barricades and warning devices as the hole and dirt attract their attention. They may crawl under or over the barricade and fall in. A strong wind could knock the barricades over. The battery for the light and beeper may fail. A warning sign in English may be installed, but someone may not be able to read or understand English. The complexities of a seemingly simple problem often make it difficult to eliminate or control a hazard.

In the process of hazard recognition and control, one must identify the complexities of contributing elements. The hazards must be considered in their use environment. A number of conceptual models help one think of the many elements that contribute to incidents. Individually, people, machines, environments, materials and other factors may not create hazardous conditions, but when put together in certain situations, they may create a danger or increase the likelihood of an incident. The selection of controls must consider the complex array of elements potentially present.

Four Ms

One conceptual model illustrated in Figure 3-2 is the "four Ms": man, media, machine, and management.[7] Media can be thought of as environment. The model helps one think of the many factors and their interrelationships that contribute to potential incidents. The model helps when trying to select effective hazard controls.

Goal Accomplishment Model

Another conceptual model is the goal accomplishment model. Figure 9-3 illustrates this model. It assumes that

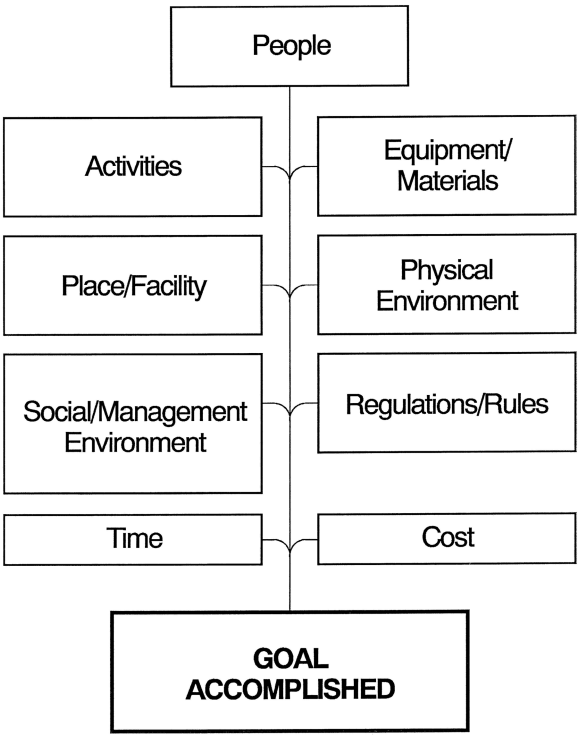


Figure 9-3. A goal accomplishment model for identifying and controlling hazards.

TABLE 9-3 Factors in the Goal Accomplishment Model

Factor	Typical characteristics
People	Age, gender, size, strength, training, knowledge, emotion, state of health, culture, attitudes
Activities	Sensory and motor skills, actions taken
Equipment	Machines, vehicles, systems, materials, supplies, containers
Place	Facility, building, land area, road, air space, waterways and their characteristics
Environment	Thermal, electrical, sound, chemical, illumination, radiological, biological
Social/Management	Organizational and work climate, interpersonal relationships, environment communication, language
Regulatory/Procedural environment	Laws, regulations, procedures, policies, work rules and practices, rules of the road, etc. (both written and unwritten)
Time	Time available, rates, shifts, work hours, changes in shifts
Cost	Initial cost, operating cost, rent, losses, medical cost, repair cost, replacement costs, demolition or decommissioning costs, etc.

people and organizations are goal-oriented. The model includes nine factors that groups use to accomplish a goal. People (1) perform activities (2) and use equipment (3) to help them. People perform the activities in some place or facility (4) under the constraints of physical (5), social (6), and regulatory (7) environments. There are time (8) and cost (9) limits for the activities. Each of these factors has many characteristics that influence goal achievement (see Table 9-3). One can analyze situations for hazards while considering these nine factors. The thought process will help identify what can go wrong in reaching the goal and when selecting hazard controls.

9-7 SOME BASICS

Housekeeping and sanitation are fundamental in preventing injuries and illnesses. When incidents do occur, first aid or emergency action can reduce the severity of losses. People often overlook these basics. Industrial workers fought hard to achieve some of these privileges and in less developed countries workers are still fighting to get them. Because of their importance, there is a need to make a few comments about them. While working through the many details of safety and health, these fundamentals also require attention.

Housecleaning and Housekeeping

One way to control hazards is through housecleaning and housekeeping. Housecleaning involves picking up, wiping up, and sweeping up. It includes organized collection and removal of scrap and waste.

Good housekeeping reflects the adage "having a place for everything and everything in its place." Not having proper storage places and storage equipment often creates housekeeping problems. Some people would delegate housecleaning and housekeeping to janitorial services, but everyone should share the responsibility for them.

Lack of housecleaning and housekeeping creates hazards. It is a symptom of unorganized, unplanned, and sloppy work and offers a visible representation of poor work management methods. In fact, many companies find that good planning and organization of work solve many housecleaning and housekeeping problems. Good planning, organization, and timely execution create profit. One can often tell how well an organization planned, organizes, and manages and how profitable it is by simply observing the housecleaning and housekeeping.

Housecleaning has another aspect. Some waste materials are hazardous. Any waste collection and management method must account for those hazards. A janitor who removes waste after hours may have no knowledge of the hazardous materials that have been left for removal. Hazardous materials require special waste management and disposal.

TABLE 9-4 Important Sanitation Practices

1. Proper design and operation of sanitary and storm sewers.
2. Availability of safe drinking water and clean dispensing equipment.
3. Clean, operable toilet facilities.
4. Frequent garbage, scrap, and waste removal.
5. Proper management and removal of hazardous waste.
6. Sanitary food preparation, service, handling and eating areas.
7. Insect, rodent, and other animal and bird control.
8. Sufficient and sanitary cleanup areas, locker rooms, and showers.
9. Use of appropriate personal protective equipment and clothing.

Sanitation

Sanitation is another important concept related to safety and health. Sanitation refers to adequate and clean restrooms and eating areas free of contaminants. Sanitation includes control of rodents, birds, and other sources of germs that transmit diseases. Control of health hazards requires sanitation. A variety of sanitation practices control disease transmission and ingestion, or contact with toxic or hazardous materials. Table 9-4 list key sanitation practices.

First Aid and Emergency Action

Treating injuries immediately can reduce their severity and prevent further injury or illness. Trained personnel, who know the correct treatment, should administer first aid and maintain records of treatments. Each facility should have adequate first aid and injury supplies and equipment. This will include appropriate special equipment, such as deluge showers and eyewash fountains. Supplies and equipment should be at locations where there is a potential need. It is also important to maintain first aid supplies, equipment, and training.

Emergency action helps reduce the severity of an incident. Emergency action may take several forms, for example, evacuation, rescue, emergency communications, treatment, and recovery. Emergency action requires the use of specially trained teams (fire brigades, spill response teams, etc.) and special equipment (fire protection systems, spill containment equipment, flood control equipment, communication systems, medical emergency equipment, etc.). Chapter 29 discusses emergency actions in more detail.

EXERCISES

1. Identify hazards in your place of work or residence, applying the four Ms model and the goal accomplishment model.

2. Discuss the importance of communication for safety and cases of communication errors or failures with

(a) a communication specialist

(b) a safety professional

(c) an attorney

REVIEW QUESTIONS

1. What is Murphy's law?

2. What is a hazard?

3. What is hazard control?

4. What are the sources of hazards?

5. What are the four components of communication?

6. What are the priorities for hazard control?

7. What are the general effects of exposures to hazardous environmental conditions?

8. What is a latency period?

9. What range in time can a latency period cover for various exposures to hazardous environments?

10. Do all people exhibit the same response to exposures to environmental hazards? If not, why?

11. What three items of information does one need to evaluate an exposure to an environmental condition?

12. How does one know if an exposure is hazardous?

13. How does one acquire information about an exposure?

14. What are the elements in the four Ms model?

15. What are the elements in the goal accomplishment model?

16. How are housecleaning and housekeeping related to hazards?

17. Explain the following terms:

(a) redundancy

(b) single point failure

(c) safety device

(d) safety warning

18. Why do procedures have the lowest priority in the list of hazard controls?

19. Why is personal protective equipment included with procedures?

NOTES

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4 *NIOSH Pocket Guide to Chemical Hazards*, National Institute for Occupational Safety and Health, Washington, DC, updated periodically. Available at: www.cdc.gov/niosh/npg/

5 www.epa.gov

6 *Threshold Limit Values and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, annual. Available at: www.acgih.org.

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CHAPTER 10

MECHANICS AND STRUCTURES

10-1 INTRODUCTION

Many accidents and injuries result from forces which are too great for a structure or a material. An important part of engineering is the field of mechanics, the study of forces and their actions. To make systems, devices or products safe, engineers must account for the types and amounts of forces that act or might act on them. In addition, engineers must account for the forces from objects that may act on the human body and its tissues. The strength of human tissues is usually below that of other materials.

In engineering mechanics, there are many specialized fields and this chapter cannot review them all. The aim is to look at some of the fundamentals and their relationships to safety.

10-2 ELEMENTS OF MECHANICS

Forces, Distribution, and Materials

Clearly, the size or magnitude of a force acting on an object is important. Large forces are more likely to cause failure or damage than small ones.

How a force acts on a body is also important; a force may act in one or more directions; it may act over a small or large area. These characteristics are also important for safety. A 50-lb force applied to the edge of a sheet of glass and parallel to it may not break it. If a hammer strikes the center of the sheet with the same force, the glass will probably break. A wood panel of the same size undergoing the same force, will not break. Those involved in safety need to understand how forces work.

When evaluating the strength of a material, it is essential to evaluate the distribution and concentration of forces as they act on bodies. Figure 10-1 gives some examples of distributed and concentrated loads.

Stress is the unit force applied over an area. A 10-lb box that is 10 inches square sitting on the floor creates a stress of 10 lb/(10 in × 10 in) = 0.1 lb per sq in. The total force of the box on the floor is 10 lb.

Through experience, we know that different materials have different strength properties. Glass shatters easily compared to wood or metal. The ability to deform can affect the strength of a material. Important properties of materials include strength, brittleness, ductility (ability to bend or deform), thermal expansion and contraction, shape, age, exposure to environmental conditions, and exposures to chemicals.

The strength of a material varies with how forces act on the materials. Forces may pull, crush, twist, or cut (shear). A material may not have the same strength for every kind of force.

A key relationship between a force, F, and a body on which it acts is:

$$F = sA \tag{10-1}$$

where

s = force per unit area or stress (such as pounds per square inch)

A = area (such as square inches) over which a force acts

The stress that a material can withstand is a function of the material's strength properties and the type of loading.

If designers know the load that will apply to a material and the area over which the load acts, they must determine if the material can withstand the load safely. In other cases one estimates the expected force first and then selects the material and designs for the load area.

A designer must envision the use environment. For example, building designers must determine the weight of building components and potential loads from building contents, wind, snow, rain, ice, and earthquakes. The designer of a wrench must consider how hard a user can pull on it. The designer of a toy must estimate how hard a child (young or old) can push or pull on it and how the toy's surfaces may interface with human tissue. The toy designer should even consider the impact forces of someone falling on the toy.

The forces that an object can encounter are often different from the forces that an object can withstand. For example, designers of breakaway sign posts and light poles along highways want the structures to fail at loads lower than

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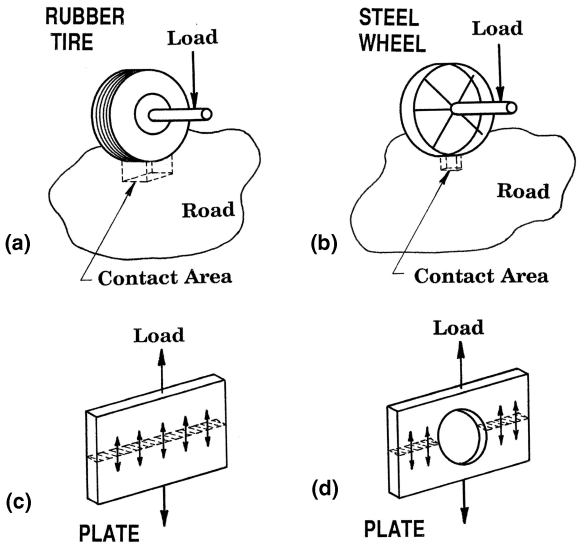


Figure 10-1. Examples of distributed and concentrated forces. In (a) tire flexion distributes the load over a larger road area than does the steel wheel in (b). The hole in the plate in (d) concentrates the load over a smaller internal area compared to the plate without a hole in (c).

they will actually encounter. The goal is to allow the sign post to break if struck by a car rather than withstand the impact forces from the car. That way, there is less damage to the car and potentially less injury to its occupants. The designer of a toy may want the toy to fail and fail safely rather than damage body tissue when a child falls on it.

In other cases, the designer may want a structure to withstand the greatest possible load. For example, the design for a roof should withstand a strong wind or the weight from a 50- or 100-year snow fall.

Safety Factors

Factors Impacting Properties of Materials There are many variations that affect the load capacity of a material. When working with a material, users do not always know that the material is uniform and has exactly the same properties throughout. The material may have irregularities or be non-homogeneous. After repeated use or exposure to weather or other environments, the material may lose some of its strength or suffer a change in properties. There may be corrosion or wear. Parts may differ a little because of variance in a manufacturing process. Temperature may affect the properties of a material. Planned loads may be uniform and static, but actual loads may not have the planned distribution or be dynamic.

These variations make it difficult to predict exactly how a product or part will perform. One way designers deal with such variations is by applying a *factor of safety* or a *safety factor*. Equation (10-1) will add the factor as a multiplier. Usually, the value is greater than 1.0 to allow for stresses or loads greater than planned in a design. On occasion, the value may be less than 1.0 to assure that failure occurs below planned loads.

CASE 10-1

Below are several situations in which failures of parts and structures caused injury and death.

10-1a April 27, 1978. In West Virginia 51 construction workers fell 170 feet to their deaths as the scaffold and form work system peeled from the top of a cooling tower under construction. The lack of some required bolts connecting the scaffold to the tower and inadequately cured, insufficient strength concrete contributed to the accident.[a]

10-1b May 30, 1979. A DC-10 crashed on takeoff at Chicago O'Hare Airport, killing 273 people. A 3/8 inch diameter bolt supporting the engine pylon failed, causing the engine to break away from the wing. As it broke away, it ripped through three redundant hydraulic flight control lines[b] causing the crash.

10-1c August 1, 2007. A portion of an eight-lane, 1,907-foot bridge on I-35 W in Minneapolis, spanning the Mississippi River, collapsed during rush hour. Some 111 vehicles fell 108 feet, 17 into the river. Thirteen people died and 145 received injuries. The report of the National Transportation Safety Board cited several contributing factors.[c] Built in the 1960s, contractors making repairs loaded materials and equipment onto the span. Over the years, pavement resurfacing and other changes had increased the load. The original design, often used at the time, was a "fracture critical" design in which the failure of any major member would cause a collapse. There was no structural redundancy. NTSB also cited contributing factors from inadequate calculations and inspections for main truss gusset plates.

10-1d 1995. A worker stepped on a plastic skylight on a roof to gain access to an air conditioning unit he was repairing. The plastic cover failed. The worker fell through the skylight opening to a concrete floor in the plant. The worker became a quadriplegic. Ultraviolet light had caused the plastic to deteriorate and lose much of its strength.

[a] www.nist.gov/customcf/get_pdf.cfm?pub_id=908824

[b] NTSB Report AAR-79-17; NTIS publication UB/E/104-017.

[c] www.nist.gov/customcf/get_pdf.cfm?pub_id=908824

Safety Factors Technically, a safety factor (SF) refers to the ratio of a failure-producing load to the maximum safe stress a material may carry. Some call the maximum safe stress the *allowable stress*. Failure may not be by rupture or fracture. A failure could be a change in area or properties of the material that affect the load-carrying capacity and its safety.

Setting Safety Factors Laboratory tests place materials under controlled loads, usually stretching the material. For example, the allowable stress for steel is the point at which the material starts to stretch or yield excessively. The testing machine plots the load and stretching and creates a diagram (a load per unit area and unit elongation or deformation). The strength for steel is the yield point on the diagram. For other materials the allowable stress is the ultimate strength from similar tests. Consult references on strength of materials for more details about test methods and stress-strain diagrams.

There are many ways to determine a safety factor SF. One common way is

$$\text{SF} = \frac{\text{failure producing load}}{\text{allowable stress}} \qquad (10\text{-}2)$$

Experience with a material in question and knowledge of its properties and applications usually determine a safety factor. Decisions on safety factors should include analysis of risk and potential consequences of failure. Different safety factors may be appropriate for different applications and use conditions for the same material. Usually, the safety factor will be higher for materials with less homogeneity. Safety factors are higher for sudden, dynamic loads. Designs that anticipate reductions in cross-sectional areas of a component through wear or some other change in properties may incorporate higher safety factors. Regulations and standards specify some safety factors.

In safety engineering one must be very careful in using data from tables dealing with strength of materials. Some tables include a factor of safety, while some do not. Using strength data in error from a table that does not include factor of safety poses a significant risk. Users of a table that includes a factor of safety must also apply data carefully to ensure that the assumed safety factor is suitable for the actual use conditions.

Field Use Tables Some load and strength tables are for field use, that is, use in daily operations or activities. Most field use tables incorporate appropriate safety factors. Having the safety factors included in tables eliminates a potential computational error. Field personnel who have to perform computations and complex interpretations of data tables are more likely to make errors as the number of steps in using a table increases. Field tables should reflect the decision tasks and situations expected during operations.

Kinds of Forces and Stresses

If one were to slice an object that is under external load, one can describe the kind of stress acting on the object. The key is the direction in which the stress acts relative to the plane of the section. Figure 10-2 illustrates several examples. Stresses acting perpendicular to the plane are normal stresses; they can be tension or compression stresses. Stresses acting parallel to the plane are shear stresses.

The way forces act on an object helps to classify them. Forces that pull an object apart are *tensile forces*. Those that squeeze an object are *compression forces*. Those that cut an object are *shear forces*. Those that twist or turn an object are *torsional forces*. Those that cause an object to bend are *bending or flexural loads*. When one object acts on, presses against or bears on another, the force of one on the other is a *bearing force* or *load*.

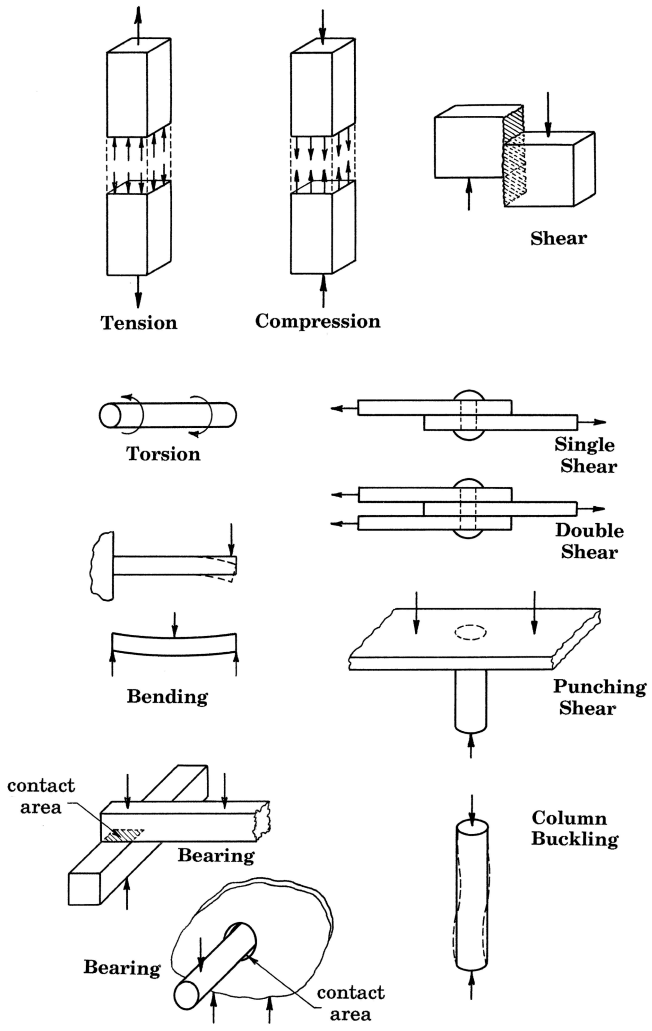


Figure 10-2. Examples of different kinds of stresses and forces.

10-3 MODES OF STRUCTURAL FAILURE

Materials and structures can fail in several ways. The main modes of static failure are shearing, tension, compression, bearing (crushing or deforming), bending, and buckling. Names for most modes of failure come from the kinds of forces applied.

Beside static loads, dynamic loads can cause materials to fail. Impact failure and fatigue failure are dynamic failures. The ability of a material to withstand an impact load gives rise to a property called toughness. Dynamic loads, continually changing loads, can change the strength, ductility and other properties of materials. Dynamic loading itself or the changes in material properties that result can cause fatigue failures.

Instability is a form of failure for an object, rather than a failure of some material it contains. *Tipping over* is a common instability failure. If the resultant forces on an object act outside the support area or exceed the capability of anchors, the object will fall over. Failures of structural components can shift loads so that instability results. Rectangular frames are less stable than triangular ones, because their joints act as hinged joints. Rectangular bases are more stable than triangular ones, because the base extends over a larger area. Gravity, friction, inertia of a moving mass, or externally applied loads may contribute to the resultant force, the overall collection of forces acting together. To help maintain stability, football players will spread their feet apart to increase the support area or get support by placing their feet in line with the resultant force. If both feet are close together, another player can knock a player over easily. A crane may tip over when an excessive load is outside the support area. That occurs when the resultant force acts outside the support envelope of wheels, tracks or outrigger pads.

Tipping over also occurs when inertia adds to static forces. For example, a crane can tip over when the lifted load starts to swing. A vehicle going around a corner can tip over because the centrifugal force is greater than the resistant force of the tires on the surface. A truck trailer passing through a cloverleaf ramp on a highway can tip over if the load inside shifts and creates a larger centrifugal force than that created during the turn.

Other forms of instability are worth noting. During construction of buildings, it is important to add cross-bracing for rectangularly arranged structural components. Torsion and lateral loads created by wind or the materials of construction can lead to collapse, even when the load-carrying members of a building are in place and adequate. A tilt-up concrete wall panel will tip over without adequate bracing.

A stepladder depends on spreaders and cross-bracing to keep the legs of the ladder in position relative to one another. Because of the slope of the legs, a torsional load occurs when someone climbs the ladder. The ladder has a tendency to twist and buckle without adequate bracing. It is also important that spreaders be fully down and locked. If they fold up or are not fully in place to start with, the ladder can collapse.

Another form of failure for some materials is *creep*. Creep is a very slow, but permanent deformation of a material under load. Some plastic materials are subject to creep failures. The cross-sectional area of a part may change and weaken the part as a result of creep. Another example is aluminum electrical wire. During a shortage of copper in the late 1970s, manufacturers substituted solid aluminum for solid copper in some electrical wiring applications. Tight connector screws became loose later as the local load of the connector on the aluminum wire caused creep in the aluminum material. That does not occur for copper wires. In some cases the loose connections for aluminum wires eventually led to arcing and fire.

Other changes in properties of a material can lead to failures. For example, exposing some metals to caustics will make the metals more brittle. *Brittleness* increases the likelihood of fractures or other failures. Exposing materials to ionizing radiation may reduce strength and increase brittleness. Exposing some plastics to ultraviolet radiation, such as from sunlight, will change the strength properties (see Case 10-1d). Dynamic loading of some ductile materials will make them brittle. Freezing may make some materials brittle, while heating may simply reduce the strength of others. Getting some materials wet may significantly change their properties. For example, wet cardboard products have very little strength.

An object will have several modes of failure. One must analyze the possible kinds of loads and modes of failure. Analysis for each mode will determine which mode of failure is most likely for each condition. Completing such analysis is a task for designers.

10-4 CAUSES OF STRUCTURAL FAILURE

There are many different causes of failure. One scheme for classifying structural failures is the following: design errors, faulty materials, physical damage, overloading, poor workmanship, and poor maintenance and inspection practices.

Design Errors

One form of design error is incorrect or poorly made assumptions. For example, a designer may assume some load or a maximum load as the basis for a design. The actual load may be very different in normal, adverse or misuse

conditions. In selecting a load for design, one may make trade-offs with cost and other factors. For example, here are some typical issues for a designer in estimating the load on a hand-operated lever:

- How hard can someone push or pull on a lever, given their posture?
- Is the 95th percentile male strength data found in a design handbook a good choice?
- Should one use a value for two people pulling on the lever?
- Will using a "cheater pipe" or extension on the handle of a ratchet wrench overload it?

Another form of design error is assuming a static condition or load when a dynamic one is more representative of the real conditions. The collapse of the Kemper Arena roof in Kansas City in 1979 provides an example. The roof hung from external structural beams extending above and across the roof. Hanger bolts attached the roof to the external beams above it. The roof swung a small amount from its suspension during windy conditions. The hanger bolts supporting the roof from an external space frame were high strength steel. Designers chose this bolt material because of its overall strength. However, there was no dynamic performance data for that new material at the time. Later test data on similar bolts of the same material showed a rapid reduction in strength each time someone tightened and loosened a nut. The tightening created a tensile load. When loosened, the strength of the bolt decrease significantly. Some engineers believe that the dynamic loading of the roof bolts reduced the strength of the bolts to the point at which the bolts could no longer support the roof.[1]

Designs that are difficult to fabricate or assemble are another kind of design error. The error can result from lack of practical experience on the part of a designer or from improper implementation of a design in the field. For example, a welder may not have experience with special welds called for in a drawing.

Computational errors are another form of design error. Manual calculations or errors in computer programs can lead to structural failure if designers do not check or validate computations.

Another form of design error can be poor material selection. A selection error may result from lack of knowledge or data about particular materials. Similar materials may have different properties that are critical. A selection error may result from lack of knowledge or from lack of field data or test data about a use environment. Selection of incompatible materials may induce or accelerate corrosion and fatigue, increase brittleness, or cause other effects that reduce the strength of the material.

Another form of design error involves specification of materials. A designer may have selected the right material, but the specification communicated to and used by buyers may lack precise information for purchase. For example, a designer may want a lubricating oil with a particular flammable property that will minimize the danger from fire. Similar oils, while matching other requirements, may not have that required property.

Faulty Materials

Two factors that can affect the safety of materials are lack of homogeneity and changes in properties over time. Homogeneity refers to the uniformity of a material or the similarity among several samples. Wood, for example, has knots and grain variations that affect strength within one board and among many samples. Cast and molded materials often have voids in them or irregularities. Some materials, like glass, may have internal stresses that result from uneven temperatures during manufacturing. Poorly mixed composite materials may have uneven distribution of components. For example, a tiny flaw in the turbine wheel may have caused a United Airlines DC-10 crash in Iowa in 1989. The wheel flew apart and ripped out hydraulic lines that controlled the flight of the aircraft.

One way to control homogeneity is through testing. Another way is grading of materials, like wood. In some cases, the cost to assure homogeneity is too high. A proper factor of safety or accurately estimated operational loads can help compensate for non-homogeneity. Redundancy in structural components that prevent collapse if one element fails is another design consideration.

Changes in properties of a material over time take many forms. Changes that affect strength are very important. Other properties, like ductility, brittleness or toughness, are also important. The changes may result from corrosion, dynamic loading, vibration and noise, rotting or decay, wear, and exposure to sunlight or other radiation, salt air, chemicals, water or dissimilar materials. By anticipating the use environment, designers can prevent or minimize changes or extend safe use. Designers can also specify proper selection, use, maintenance, inspection, and special treatments.

Physical Damage

Use, abuse, and unplanned events can change the strength, dimensions, and conditions of materials. Damage to one element may not cause failure directly. However, when a load shifts to other elements of a structure, the other elements may not withstand the load change.

Placement is one control that may minimize physical damage. A house or other building placed very close to a railroad track is likely to get hit should a train derail at that location. Someone will likely hit a mailbox placed right next to the pavement of a road compared to one set back. Someone will probably run into or trip over objects protruding into an aisle of a storage area.

Another control is the use of barriers. Placement of wires in conduits will reduce the potential for damage to the wires. Light bulbs in trouble lights have a protective metal cage. Raised concrete islands and concrete-filled steel columns protect gas pumps in service stations. Heat shields in automobile engine compartments protect some components from thermal damage.

Another control is structural design that allows for some damage. For example, a standard for warehouse storage racks requires that damage to one leg of a four-legged structure should not cause collapse of a rack. A rack must stand even when one leg does not support a load. The standard recognizes that forklifts or other equipment may strike a leg of a storage rack during operations.

Overloading and Inadequate Support

Conditions change in the use environment. When not foreseen by a designer or user, the changes may result in overloading or inadequate support. For example, an owner converted a warehouse in Florida to offices. Because there was inadequate parking for employees (not a problem for the prior use), the renovation design converted the roof into a parking deck. When the roof collapsed, it became obvious that the roof could not support the weight of vehicles.

In another example, a manufacturer designed a flatbed truck trailer to carry uniformly distributed loads of bagged material. When used to haul an earthmover with concentrated loads on the outer edges, the sides collapsed. There were no outrigger supports for the portion of the bed that extends outward from the support beams.

Inadequate support refers to an object or structure not having enough load-carrying capacity for its uses. If designers or users do not foresee the potential use situations, failures can result. There are many examples. If an operator sets supporting outriggers of cranes or backhoes in mud or disturbed soil, the soil may compress and allow the machine to tip over. The legs of tubular scaffolds are fine when they rest on concrete. When they rest on soil, the legs will sink into the soil and the scaffold will tip. Bearing plates placed under them on soils will limit sinking.

Soil with a certain moisture content provided a firm foundation for the Winchester Cathedral in England when it was built. When town officials diverted a nearby stream, the soil compacted as it dried and caused a corner of the cathedral to sink. Damage prevention shored up the foundation to prevent the cathedral from collapsing.

Vibrations from tracked earthmoving equipment can travel through the soil and cause the walls of nearby excavations to collapse. Nearly every rainy season in southern California, homes slide down hills because wet and saturated soils can no longer support the loads. Stacking cartons too high may cause the carton at the bottom to collapse. Then the stack will tip over. Structures for many facilities under construction are adequate when completed, but have significant weak points during construction.

Poor or Faulty Workmanship

Other causes of structural failure are improper assembly and maintenance. Some failures may result from human error or may be due to designs that are difficult, impractical or impossible to implement. Some may simply result from careless work and poor decisions on the part of workers and management. Sometimes several causes combine and lead to failure. Lack of communication, skill, knowledge, training, procedures, and management commitment can all contribute to faulty workmanship.

One theory for the cause of the collapse of the Hartford CT Coliseum roof in 1978 is that workers did not assemble some joints as specified in design drawings. The original design allowed a 160,000-lb load through the center of the connecting plate and a moment of 0-ft-lb. As actually fabricated, the joint created a 15,440-lb pound load and a 9,490-ft-lb moment.[2]

Another form of faulty workmanship is a change in procedures, particularly when decision-makers do not fully consider consequences of the change. One example is the DC-10 crash in Chicago in 1979 (see Case 10-1b). The manufacturer's maintenance procedure called for the engine to be removed first, then the pylon that attached the engine to the wing. To save time, workers suggested changing the procedure to remove both engine and pylon at the same time. Some believe this practice may have placed excessive loads on the connection between the pylon and the wing. Studies after the crash found cracking of connection elements and ultimate failure.

Poor Maintenance, Use and Inspection

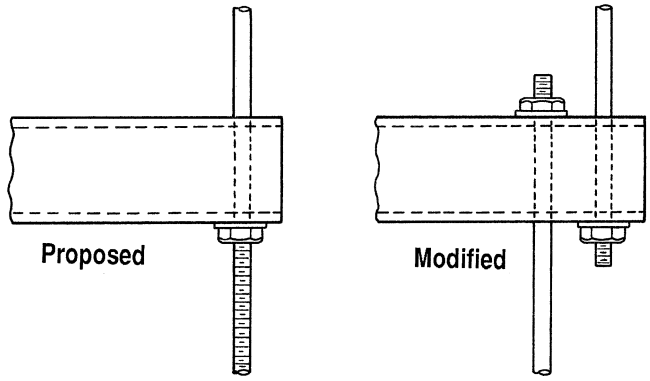
Materials, products, structures, and buildings do not always stay the way they were manufactured, assembled, or constructed. Exposure to various conditions during their life will change them. Designers should specify proper maintenance to prevent corrosion or damage. Improper use can affect the likelihood of structural failure. Even normal use can affect structural integrity. Inspections need to identify worn components and initiate replacement. Corroded elements may need strengthening or replacement. Inspections are an important means of identifying changes in properties. Depending on a product and its potential changes, there is a wide range of inspection methods. In some cases visual inspection is not sufficient. Some inspections require specialized and sophisticated equipment to assess the condition of structures and their components.

CASE 10-2

July 17, 1981. During a festive event at the one-year-old Hyatt Regency Hotel in Kansas City, two walkways collapsed, killing 113 people and injuring 186 others. It was the deadliest structural failure in US history. The walkways crossed the large, multi-story atrium to create aesthetic views. On the night of the collapse, people attending the gala event filled the walkways.

There were many investigations representing different parties potentially involved in the design and construction. Hundreds of news and professional articles followed the event, study results and later legal and ethics actions. The overall conclusion was the inadequate design of the supports for the walkways.[a]

The walkways hung from rods that protruded through box beams that supported the walkways. The design required workers to thread supporting nuts several feet along the threaded rods. Because that task was difficult and slow to complete, engineers on site changed the design. The change doubled the shear load at the lower supporting nut on the box beam. The nuts pulled through the box beam[b] (see Figure Case 10-2).



Case 10-2. Changed load on box beams. The original design placed the load from a skywalk on rods with threaded nuts below the box beams at each level. The onsite modification placed the load of a lower skywalk on the box beams of an upper skywalk, thus placing a double load on each supporting rod and nut. The nuts below the box beams (supporting both levels) pulled through the box beams.

In the original design, the load on each skywalk involves only its own weight and bears on one supporting nut below the box beam for each supporting rod. A modification placed the load of a lower skywalk onto the box beam of a skywalk above it. As a result, loads from two skywalks bear on the box beam of the upper skywalk.

[a] http://fire.nist.gov/bfrlpubs/build82/PDF/b82002.pdf

[b] "Altered Design Probed in Hyatt Collapse," *Building Design and Construction*, September 17–18 (1981).

10-5 EARTHQUAKES

Earthquakes result from the movement of the subterranean plates forming the Earth's surface. The movements between plates typically occur along fault lines. Earthquakes occur suddenly. Most last about a minute or less, but some last longer. Smaller tremors may occur for days and weeks after the initial earthquake. Depending on severity, building design, and other factors, earthquakes can cause major damage.

The Richter scale, a logarithmic scale, is a measure of earthquake intensity or energy released during the plate movement and the surface wave magnitude. An earthquake of magnitude 6 on the Richter scale is ten times greater than one of 5. An earthquake of magnitude 9 is 1000 times greater than one of 6. A magnitude 8 earthquake occurs somewhere in the world annually. A magnitude 7 occurs somewhere about weekly.

Earthquakes originating under the sea can create ripples on the surface. A ripple may travel at rates of 300 to 400 miles per hour for a thousand miles or more. A tsunami is a large ripple.

An earthquake causes the ground to vibrate at low frequencies. Any structure that has flexibility and can stretch to some extent or bend through connected joints has a greater chance of sustaining the vibration of the earth than a structure that has little joint strength.

Some vibration is vertical. Much is horizontal and causes some structures to move from their foundations. Vibration causes items to fall from shelves and walls. It causes windows and walls to crack. The damage many be small or large, depending on a variety of factors.

Mortar joints found in brick, concrete block and stone structures are brittle and are not likely to withstand the structural flexion resulting from an earthquake. Mortar-constructed walls have high bearing strength, but little shear or bending strength (see Figure 10-2).

Some additional mechanics of soils can come into play during an earthquake. Because of the moisture content and the makeup of some soils, vibration from an earthquake will make them behave much like a liquid during the vibration. Under normal conditions the soils act like a solid.

CASE 10-3

On February 22, 2011, a 6.3 earthquake struck the region around Christchurch, the second largest city in New Zealand, killing 185 people. There were many aftershocks. About six months later on September 4, 2011, another magnitude 7.1 earthquake struck the same area with no fatalities. Significant liquefaction produced about 400,000 tons of silt.

There were major interruptions in electricity, sanitary sewer and other utility services. One thousand of 4,000 buildings in the city center required demolition. Of the 220 buildings that were five or more stories tall, 110 were no longer useable. Nearly 100,000 homes received damage and about 10,000 required demolition.

Overall, the earthquakes produced about $40 billion in damage that may take New Zealand's economy 50 years or more to recover completely. A detailed government report[a] provides details and many design recommendations.

[a] http://canterbury.royalcommission.govt.nz/

Liquefaction is the shift to liquid properties during vibration. Soils that exhibit liquefaction during an earthquake are man-made fills. Some are ancient lake bed sediments or simply soft soils. Much of Mexico City and towns and cities in the area around the New Madrid Fault exhibit liquefaction. The New Madrid fault extends between Memphis, Tennessee, and southeastern Missouri. For soils subject to liquefaction, damage is likely to be significant. A common reason is foundation designs rely on normal soil properties rather than the "liquified" properties.

Another earthquake-related phenomenon affecting structures occurs when the frequency of vibration in an earthquake is at or very near the resonant frequency of the structure. The amplitude of the vibration becomes amplified and the degree of damage is significantly greater than expected from the earth's movement from the earthquake itself. Elevated highway structures have exhibited unexpected damage from earthquakes involving this effect.

When an undersea earthquake occurs, it can cause a tsunami, a large wave effect. The normal water elevation changes and large amounts of water can wash into built-up areas causing severe damage from the energy produced by the moving water or from the flooding. The earthquakes cause a surge through the water that results in excessively large waves as the energy in the surge approaches the shore. In shallow areas, a tsunami can wipe out the entire built-up area and most of the population located there. Usually the water's action occurs much faster than anyone can react. The force of the moving water can knock down structures and move people and vehicles uncontrollably. In recent years, a tsunami warning system has been created for some locations subject to undersea earthquakes.

Many locations are in seismic zones that denote the likelihood and severity of potential earthquakes. It is important to know the seismic zone for any location and to follow the latest designs for buildings and structures for such zones to ensure the greatest degree of structural stability and to achieve the minimum amount of damage from an earthquake. For locations subject to structural property changes in soils or subject to potential tsunamis, other design considerations may apply.

CASE 10-4

On December 28, 2004, a near-record earthquake of magnitude 9.2 occurred along the floor of the Indian Ocean off the west coast of the Indonesian island of Sumatra.[a,b] Some estimated the energy of the quake equivalent to 23,000 atomic bombs. The rupture in the earth's surface was about 600 miles long, 10 yards wide horizontally and several yards vertically. Trillions of tons of rock moved in the event on the sea floor.

The quake produced tsunamis that struck coasts of 12 countries, as far away as 3,000 miles. Although no one will know the exact death toll, there were more than 131,000 confirmed deaths. In addition, there were 37,000 more missing. The tsunami displaced more than 500,000 people from their homes in Sumatra alone. Overall, estimates indicate as many as 5 million people lost homes or access to food and water.

For some, the tsunami affecting an area occurred several hours after the initial quake. Most victims had no warning because there was no tsunami warning system in that area of the world.

[a] http://news.nationalgeographic.com/news/2004/12/1227_041226_tsunami.html

[b] www.unep.org/tsunami/reports/TSUNAMI_report_complete.pdf

CASE 10-5

Many regions of the world where earthquakes are likely have adopted design standards that make buildings tolerant to earthquakes. Many areas that face danger from hurricanes have building design standards for continuous winds.[a,b]

Someone asked whether there are design standards for tornados. There are recommendations[a,c] especially related to connections between a foundation and the main structure and between walls and roof structures. The aim is to keep structural elements anchored. There are also recommendations for safe rooms for family and workers.[d]

There are many difficulties when trying to design for tornadoes. In a direct hit, winds are very high. There is always a lot of flying debris that smashes windows and creates damage. The likelihood that a tornado will strike is low, since their paths are narrow and cover small areas. The odds of recurrence at the same location is even lower, creating an issue related to return on investment for expensive design features.

[a] ASCE 7-10, Minimum Design Loads for Buildings and Other Structures, available at: www.asce.org/sei/Content.aspx?id=23622324319

[b] www.mvn.usace.army.mil/Missions/Engineering/HurricaneDesignGuidelines.aspx

[c] www.nist.gov/manuscript-publication-search.cfm?pub_id=914787

[d] www.fema.gov/safe-room-resources/fema-p-320-taking-shelter-storm-building-safe-room-your-home-or-small-business

10-6 CONTROLLING STRUCTURAL HAZARDS

There is no simple prescription for the elimination and control of structural hazards. Knowledge of the technology for structural safety is essential and so is knowledge of materials and their behavior. One must complete calculations correctly and check them. Careful communication between designers and buyers or builders is important. Designers must understand the use environment. Skill and care in assembly are critical. Designers must consider the consequences of failure.

Not all structural failures cause injury, death, or major damage. In some cases a structural failure may be desirable to control the point of failure and ensure there are no catastrophic results. Some designs control the point of failure to minimize adverse effects.

10-7 APPLICATIONS

Safety engineers and others involved in structural safety must have a good understanding of the principles of mechanics. This will help them to recognize hazards and select and implement appropriate controls. A safety engineer must work with other engineers, metallurgists, architects, and other structural specialists to assure safety.

Static Mechanics

The field of static mechanics deals with forces acting on a body. Static mechanics involves bodies at rest or in equilibrium. Forces acting on them do not create motion. Common applications are bolts, rivets, welds, load-carrying components, such as ropes and chains and other structural elements. Equations (10-1) and (10-2), discussed earlier, apply to many static situations.

Example 10-1 Consider the bolt in Figure 10-3. Its load is in tension and holds two elements together. One element hangs from the other. One force acting on the bolt is the load on the lower element (100-lb load plus 10 lb for the suspended element). Another force is that caused by the tightened nut (20 lb). The total effective load on the bolt is 130 lb (100 + 10 + 20).

For a mild steel bolt, one can determine its ultimate tensile strength from published tables (60,000 lb/in.). For a 1/4 in. diameter bolt, the cross-sectional area is 0.196 in.^{2} The actual stress in the bolt, using Equation (10-1), is 130 lb/0.196 in.^{2} = 663 lb/in.^{2}

Assume for this application that a reasonable factor of safety is 3. By applying Equation (10-2), the actual factor of safety is (60,000 lb/in.^{2})/663 lb/in.^{2} = 90.5. Since 90.5 is much greater than 3, the bolt will easily carry the load.

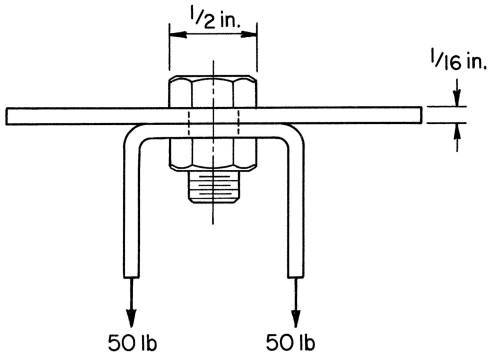


Figure 10-3. Example of tensile strength. The U-shaped member places a tensile load on the bolt.

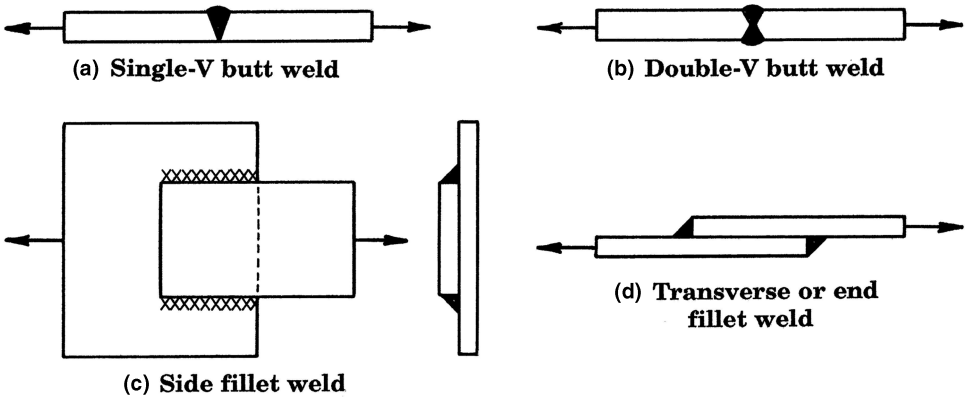


Figure 10-4. Examples of welds.

Example 10-2 The supporting plate in Figure 10-3 will fail in shear if the head of the bolt pulls through the plate. To determine the safe load capacity of the plate, one uses Equations (10-1) and (10-2). The bolt carries a 110-lb load (see Example 10-1). The outside diameter of its head is ½ in and the perimeter is $\pi \times$ ½ in. The thickness of the plate is 1/16 in. The shear area in the plate is $\pi \times 0.5 \times 0.0625 = 0.098$ in.^{2} The actual shear stress is 110 lb/0.098 in.^{2} = 1,122 lb/in.^{2} If the plate is aluminum, the ultimate shear strength is about 35,000 lb/in.^{2} from published tables. The plate will not fail in shear for the assumed load, because 35,000 lb/in.^{2} is much greater than 1,122 lb/in.^{2}

Welds

Figure 10-4 shows some forms of common weld connections. Butt welds connect two pieces that butt together. Fillet welds connect overlapping pieces.

The strength, P, *of a butt weld is:*

$$P = LtS_a \qquad (10\text{-}3)$$

where

L = the length of the weld

t = the thickness of the thinner plate of the joint

S_a = the allowable stress of the weld

The strength of a fillet weld is usually given as strength per linear inch of weld for a certain size of fillet. Because fillet welds are not often the full thickness of a plate, the size of a fillet is less than the thickness of a plate. The American Welding Society publishes weld strength data.

Dynamics

Dynamic mechanics deals with the forces acting on a body to cause acceleration. The motion may be linear and angular. Impulse, momentum, and kinetic energy are part of the field of dynamics. Table 10-1 gives a summary of the key equations for dynamics.

Many dynamic loading conditions are important for safety engineers. Some examples are deciding if rotating equipment will fly apart and whether objects striking a human body will cause injury. A forklift turning a corner too sharply may cause it to tip over. The distance needed to stop a vehicle in motion is a dynamic problem. Later chapters discuss some of these in more detail.

Friction

Friction deals with one body in contact with another that is on the verge of sliding or is sliding. Friction allows us to walk, drive vehicles, and use power equipment. The force tangent to the contact surface that resists motion is the friction force. When no motion occurs, the resistance is due to static friction. If motion occurs, the resistance is due to kinetic friction. Kinetic friction values are generally lower than those for static friction. The *coefficient of friction* μ is the ratio of the frictional force F_f to the normal force N between the two bodies

$$\mu = F_f/N \qquad (10\text{-}4)$$

Friction has limits, however. Friction will prevent motion until forces exceed the coefficient of friction. Because friction causes wear, many situations require lubricants to reduce friction and wear. Some substances become lubricants. Water, snow and ice, oils, greases, soaps, plastics, dusts, and materials with high moisture may reduce friction in locations where high friction is desirable. Examples are floors and other walking or climbing surfaces.

Example 10-3 Assume someone is about to push a large box. It may slide. It could also tip over. Which will occur, the sliding or the tipping? Assume the coefficient of friction between the box and the floor is 0.6.

Referring to Figure 10-5, one can determine what force will tip the box over by computing the moments about corner

TABLE 10-1 Summary of Mechanics Equations for Dynamics

	Linear Motion		Angular Motion	
Property	Mathematical Expressions and Formulas	Typical Units	Mathematical Expressions and Formulas	Typical Units
Displacement	s, dv, dy, dt, $s = v/2\,g$ $s = v_o t + 1/2\,at^2$	in., ft, m	dθ $s = r\theta$	deg, rad ft, m
Velocity	v, dx/dt, dy/dt, dz/dt $v = v_o + at$	ft/s, mi/hr, km/hr	ω, dθ/dt $\omega = \omega_0 + \alpha t$	rad/s, deg/s
Acceleration	a, dv/dt, d^2x/dt^2	ft/s^2, m/s^2	α, dω/dt, $d^2\theta/dt^2$ Tangential: $a_t = r\alpha$ Radial: $a_n = r\omega^2 = v^2/r$	rad/s^2, deg/s^2
Newton's second law of motion	$F = ma$ $m = W/g$ W = weight g = gravitational constant	lb_f, newtons, lbm slugs, kg	$T = I_\alpha$ $I = \Sigma mr^2 = mk^2$ k = radius of gyration	in-lb, ft-lb, kg-m^2, n-m
Momentum	$M = mv$	kg-m/s, slug-ft/s	$L = I\omega$	kg-m^2/s, slug-ft^2/s ft-lb, kg-m
Kinetic energy	$KE = 1/2\,mv^2$	ft-lb, kg-m	$KE = 1/2\,I\omega^2$	
Potential energy	$PE = Wh = mgh$	ft-lb, kg-m		
Work	Work = $1/2\,m\,(v_2^2 - v_1^2) = \Delta KE$	ft-lb, kg-m	Work = $1/2\,I\,(\omega_2^2 - \omega_1^2) = \Delta KE$	ft-lb, kg-m
Power	Rate of work, $P = Fv$	watts, hp, BTU/hr	$P = T\omega$	watts, hp, BTU/hr

B of the box. The pushing force is F and acts 4 feet above the floor. Gravity pulls the box weight (500 lb) downward at the midpoint of the box width. Each act in an opposite direction around point B at the corner of the box. The sum of moments about point B allows one to solve for the force F:

$$\Sigma M_B = 0, \quad F(4) - 500(3/2) = 0, \quad F = 188\text{ lb}$$

By summing forces in the horizontal direction, one can determine what force would cause the box to slide. Solving first for the frictional force F_f using Equation (10-4):

$$F_f = \mu N = 0.6(500) = 300\text{ lb}$$

Note that the friction force acts in an opposite direction to a pushing force. To find the pushing force that results in sliding:

$$\Sigma F_x = 0, \quad F - F_f = 0 = F - 300, \quad F = 300\text{ lb}$$

Comparing the friction force to the tipping force identifies which will occur. Because the force required to overcome friction (300 lb) is greater than the force required for tipping (188 lb), the box will tip.

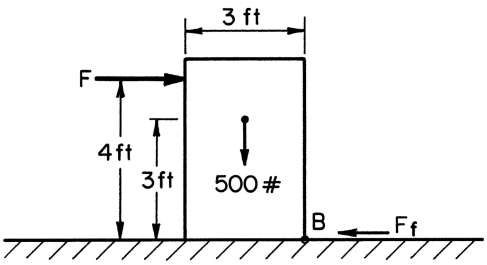


Figure 10-5. Diagram for Example 10-3.

Fluid Mechanics

Fluid mechanics is the study of forces on fluids, which are both liquids and gases. When there are only liquids involved, the field is *hydraulics*. An understanding of fluid mechanics is necessary to predict and control the behavior of fluids. Safety engineers encounter many fluid mechanics problems and applications of fluid mechanics.

A major difference between mechanics of solids and fluids is that fluids have very little shear strength. Other important properties of fluids are density, specific weight, compressibility, viscosity, surface tension, and vapor pressure.

Fluid Forces Pascal's law states that at any level a fluid exerts an equal force in all directions. For a contained column of fluid, pressure in the column will vary with the vertical location. For incompressible fluids (such as water), the pressure p along the vertical column is given by

$$p = \gamma h \tag{10-5}$$

where h is the vertical distance from the top surface to the point under consideration and γ is the specific weight (from tables of fluid properties).

Example 10-4 A tank contains oil to a depth of 25 ft (see Figure 10-6). The oil has a specific gravity of 0.9. What is the

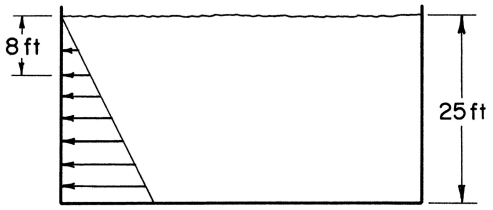


Figure 10-6. Diagram for Example 10-4.

pressure at a point 8 ft below the surface? At the bottom of the tank?

Using Equation (10-5), one can solve for pressure at the two locations.

First, solve for the specific weight of the oil. The specific weight of water is assumed to be 62.4 lb/ft^3. The specific gravity of water is 1.0. The specific weight and specific gravity for a fluid have a constant ratio, the force of gravity.

Knowing this, one can find the specific weight of the oil γ_o:

$$\gamma_o = 0.9(62.4) = 56.2\ \text{lb/ft}^3.$$

The pressure at a depth of 8 ft is then $p = 56.2\ \text{lb/ft}^3(8\text{ft})/144\ \text{in}^2/\text{ft}^2 = 3.12\ \text{lb/in.}^2$ Similarly, at a depth of 25 ft, the pressure would be $56.2(25)/144 = 9.75\ \text{lb/in}^2$.

Pressure increases linearly with depth in a fluid. Knowing this, one can develop a simple expression for the total force on a plane surface submerged in a fluid. Because the mean or average pressure p_m acting on the surface occurs at a depth located at the midpoint between the highest and lowest submerged point of the surface, the total force F is

$$F = p_m A \tag{10-6}$$

where A is the area of the submerged plane.

Example 10-5 A 10-ft-wide rectangular gate holds back water as shown in Figure 10-7. What is the total force on the gate?

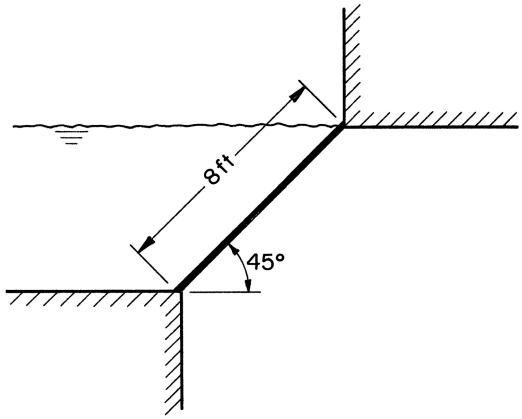


Figure 10-7. Diagram for Example 10-5.

The midpoint of the submerged gate is 8ft(sin 45°)/2 = 2.83 ft. The mean pressure is $p_m = 62.4\ \text{lb/ft}^3(2.83\ \text{ft})/144\ \text{in}^2/\text{ft}^2 = 1.23\ \text{lb/in.}^2$

The total force on the gate acts perpendicular to it (recall that a fluid exerts a force equally in all directions) and is $F = 1.23\ \text{lb/in}^2\ (8\ \text{ft})(10\ \text{ft})(144\ \text{in}^2/\text{ft}^2) = 14{,}170\ \text{lb}$.

Fluid Flow The volume flow of a fluid, Q, or discharge, through some cross-section (pipe, duct or channel) is

$$Q = VA \tag{10-7}$$

where V is the average velocity (the flow of a fluid is not uniform over its cross-section) and A is the cross-sectional area.

Equation (10-7) is the *continuity equation*. Sometimes there are correction factors added to Equation (10-7) for flow through orifices of various shapes. Chapter 25 has an example applying the continuity equation for ventilation of airborne contaminants.

In fluid dynamics the energy of a flowing fluid remains constant (conservation of energy). The form of the energy can change. A relationship that brings these energy terms together is the *Bernoulli equation*, Equation (10-8). The units are the equivalent length of a column of water or *head* represented.

The three main components in the Bernoulli equation are:

- pressure head p/γh (see Equation (10-5))
- elevation head (z)
- velocity head ($V^2/2g$).

An elevation head is the height of a fluid column relative to some vertical reference point. The sum of the elevation head and the pressure head is called the *piezometric head h*.

The Bernoulli equation is:

$$\frac{V_1^2}{2g} + \frac{p_1}{\gamma} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + z_2 = C \tag{10-8}$$

where subscripts refer to locations selected for particular applications and C is a constant for a particular application.

When fluid flows through pipes, energy may change form. For example, there are "losses" due to surface roughness, turns, valves, and other pipe components. These are shear losses and form losses. The losses reduce the velocity head. The total loss H_L in a length of pipe is the sum of losses for each component. To maintain the energy conservation in the Bernoulli equation, H_L is part of one side of the equation

$$V_1^2/2g + p_1/\gamma + z_1 = V_2^2/2g + p_2/\gamma + z_2 + H_L \tag{10-9}$$

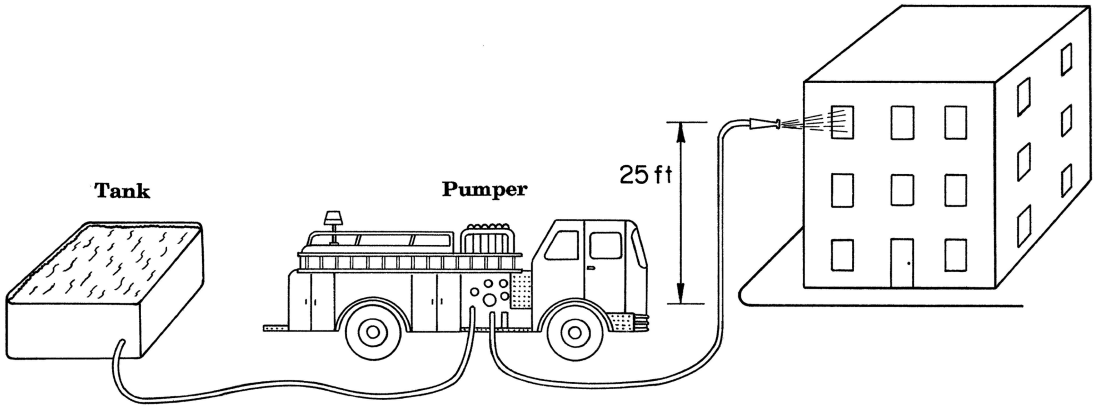


Figure 10-8. Diagram for Example 10-6.

Example 10-6 A fire truck (see Figure 10-8) pumps water to the third floor (25 ft from ground level) of a building. Water for the pump is in an open tank on the ground. The flow rate at the nozzle must be 50 gal./min. The nozzle has a 2 in. diameter opening. The pressure loss due to friction in the hose between the pump and the nozzle is equivalent to 3 ft of water. What pressure must the pump produce? Assume that a gallon of water occupies 0.1337 ft^3.

First, one must determine the fluid velocity V at the nozzle. This is determined from the continuity equation, Equation (10-7). The cross-sectional area, A, at the nozzle is $\pi d^2/4 = \pi(2\text{ in} \times 2\text{ in})/4(144\text{ in}^2/\text{ft}^2) = 0.0218\text{ ft}^2$.

From Equation (10-7), the velocity V at the nozzle is:

$$Q/A = 50\text{ gal/min}\,(0.1337\text{ ft}^3/\text{gal})/0.0218\text{ ft}^2$$
$$= 306.7\text{ ft/min} = 5.11\text{ ft/s}.$$

The velocity head at the nozzle is then $V^2/2g = 5.11\text{ft/sec} \times 5.11\text{ ft/sec}/2(32.2\text{ ft/sec}) = 0.406\text{ ft}$.

The velocity head at the tank is zero. From the given data, the elevation head at the nozzle is 25 ft relative to the pump. The pressure head at the pump and at discharge are both zero. The Bernoulli equation includes the friction component H_L.

Then, the resulting equation for this situation is:

$$C = v^2/2g + p/\gamma + h + H_L = 0.406\text{ ft} + 0 + 25 + 3$$
$$= 28.4\text{ ft water}$$

and the pump must produce a pressure of

$$28.4\text{ ft}\,(62.4\text{ lb/ft}^3)/(1/144\text{ ft}^2/\text{in.}^2) = 12.3\text{ lb/in.}^2$$

Soils

The branch of engineering that deals with forces acting on soils is soil mechanics or soil engineering. Many structures rest on soil. Road and rail transportation depend on sufficient soil strength for support.

There are many kinds of soils with different properties. Sand, for example, behaves much like a fluid. Clay behaves more like a solid. Soils engineering uses many empirical equations, because soils and their properties vary a lot. A thorough knowledge of the field and a lot of experience help to apply soil engineering practices skillfully.

Properties of Soils Literature documents many soils properties. These properties help classify soils and apply soil engineering practices. Important properties include weight, density, modulus of elasticity, internal resistance, internal friction, cohesion, and volume changes resulting from various causes.

The weight of a given soil depends on the moisture content or the amount of water it contains. The amount of solid material for a unit volume is the dry weight. Density increases by the processes of settling and compaction and decreases by disturbing soil through excavation, tillage, and other actions. The moisture content of many soils changes constantly from climatic conditions, natural or induced drainage, and compaction.

Internal resistance, which may vary for a soil, is a combination of frictional and cohesive forces acting on a soil. Several methods help determine this property. Results are often dependent on the method. Internal resistance is an index of shear resistance. Internal friction is another index of shear resistance of soils and can never exceed the value of internal resistance.

The particles of some soils tend to adhere together, whereas particles of others (sand, silt, gravel) do not adhere well to each other. The term *cohesion* means that some soils tend to hold together even when well saturated. Cohesion refers to the internal tensile strength of a soil.

Volume changes in soil result from several factors. When some soils dry out, they shrink. When moisture increases, they expand. When compressed by external loads, soils will reduce in volume. The voids between particles get smaller from the loads. Compression squeezes out the water. *Consolidation* is any process that reduces the water content of a bed of saturated soil.

Bearing Foundations must transfer the load of a structure to the soil. Equation (10-1) is a simplification of the load that a soil can support. Footings are the weight-bearing elements on which a structure rests. The actual design of footings requires more detail than represented by Equation (10-1). The footings and soil must carry not only the weight of the building and its contents, but also the loads caused by wind and other imposed loads. Soils must carry the bearing load as well as moments that may be present. Borings help determine actual soil conditions. Building codes specify the maximum bearing loads for different soils, usually in tons per square foot. These allowable values often contain a sizeable safety factor, typically from 2 to 5.

In most foundation failures, the footings seldom fail. Failures frequently involve soil compression, unequal soil compression or movement, and changes in soil conditions (water content, volume, chemical content).

Piles Piles are slender underground columns used to support loads at their top. Loads transfer to soils by the friction and adhesion along the sides of the piles and by bearing at the bottom end. Designers establish the number, spacing, size, type, and angle of piles necessary to meet the capacities of local soils and anticipated loads. Heavy equipment pounds some piles into the soil.

Retaining Walls Soils exert lateral pressure on retaining walls, much like a fluid (see Example 10-5). Soils can exert one of two kinds of lateral pressure: active pressure or passive pressure. Active pressure exists when a wall resists the tendency of a soil to slide into the wall. For example, a pile of cohesionless sand will want to form a natural slope or angle of repose. A wall that restrains this action must overcome active pressure. Active pressure includes vertical force components. Active pressure varies with soil type, geometric characteristics of the wall, and the soil restrained.

The horizontal component of active and passive lateral pressure is a function of the unit weight of soil, the square of the height of soil restrained and the internal resistance of the soil.

Another force that can add to the pressure on a retaining wall stems from poor drainage that may cause the soil behind the wall to act like a fluid. Drainage of soils behind a wall will reduce the design load on the wall.

To prevent soils from collapsing into excavations, construction uses sheeting and bracing. Designing sheeting and bracing for excavations requires knowledgeable people. Designers must analyze many factors. Qualified persons must perform the designs to meet acceptable engineering standards.

Sheeting can be flat or corrugated and made of wood, steel or other materials. There are many ways to anchor and brace sheeting. Some sheeting itself can act like a cantilevered restraint. Bracing for some sheeting may involve poles or uprights placed in front of the sheeting and embedded in soil below the sheeting. There may be braces inside an excavation to hold sheeting in place. There may also be anchors that extend into the soil behind the sheeting.

Shoring is another way to keep excavations from collapsing. Table 10-2 provides an example of data for constructing trench shoring. Figure 10-9 shows the main components. Some laws and regulations require shoring in trenches greater than 4 or 5 ft in depth[3]. The chances of soil collapse increase with the depth of excavations. Collapse is likely to be more serious when workers are below standing chest level. The laws and regulations vary.

For trenches that are not open very long and not of great depth, some use a sliding trench shield (see Figure 10-10) or portable trench box. They are a form of shoring. Excavation equipment tows it along in a trench as the machine lengthens an excavation. The trench box provides a safe area for workers. In addition to shoring, there are many other requirements for safe trenching and excavation work.

Angle of Repose During excavations, unrestrained walls will likely collapse at some point in time. No one can predict when that will occur. The collapsing soil will form some angle relative to horizontal. That angle is the *angle of repose*. The angle formed varies with type of soil, moisture content, presence of loose materials, and other factors. The same is true of soil or other bulk materials, such as grains, sand, gravel, etc., when piled up. The sides slide out and form some angle. In excavations, the walls are cut back or stepped back to an angle less than the angle of repose to reduce the danger from cave-in. Figure 10-11 illustrates typical angles of repose for various soils. OSHA has setback recommendation.[4]

Dewatering Changing the moisture content of soils can have significant effects. One effect is the change in load-bearing properties of a soil. Another is the change in soil volume.

In some locations, there is a natural level of ground water in the soil. If one digs a hole, water in the surrounding soil will fill the hole to the natural level and this is called the water table.

Pumping water from soils for construction of one facility may cause dewatering in adjacent areas and induce damage on existing foundations and buildings. As discussed earlier in this chapter, the history of the foundation of the Winchester Cathedral in the United Kingdom provides an example of dewatering when officials diverted the nearby creek. The foundation settled and caused damage to walls when the soil supporting the foundation lost moisture.

Beams

Loading of beams is another important aspect of structural safety. A load on a beam induces stresses in its material.

TABLE 10-2 Minimum OSHA Requirements for Trench Shoring[a,b]

Trench Depth (ft)	Horiz. Spacing (ft)	Cross Braces					
		Width of Trench					Vertical Spacing (ft)
		Up to 4	Up to 6	Up to 9	Up to 12	Up to 15	
5 to 10	Up to 6	4×6	4×6	6×6	6×6	6×6	5
	Up to 8	6×6	6×6	6×6	6×8	6×8	5
	Up to 10	6×6	6×6	6×6	6×8	6×8	5
10 to 15	Up to 6	6×6	6×6	6×6	6×8	6×8	5
	Up to 8	6×8	6×8	6×8	8×8	8×8	5
	Up to 10	8×8	8×8	8×8	8×8	8×10	5
15 to 20	Up to 6	6×8	6×8	6×8	8×8	8×8	5
	Up to 8	8×8	8×8	8×8	8×8	8×10	5
	Up to 10	8×10	8×10	8×10	8×10	10×105	

Trench Depth (ft)	Wales		Uprights		
	Size (in.)	Vertical Spacing (ft)	Maximum Allowable Horizontal Spacing (ft)		
			Close	2	3
5 to 10	6×8	5			2×6
	8×10	5			2×6
	10×10	5			2×6
10 to 15	8×8	5		2×6	
	10×10	5		2×6	
	10×12	5		2×6	
15 to 20	8×10	5	3×6		
	10×12	5	3×6		
	12×12	5	3×6		

[a]Refer to 29 CFR 1926 Subpart P Appendix C for details and shoring standards for other soil types.
[b]Type B soil means cohesive soil with an unconfined compressive strength greater than 0.5 tons per square foot (tsf; 48 kPa) but less than 1.5 tsf (144 kPa). Refer to 29 CFR 1926 Subpart P Appendix A for additional details.

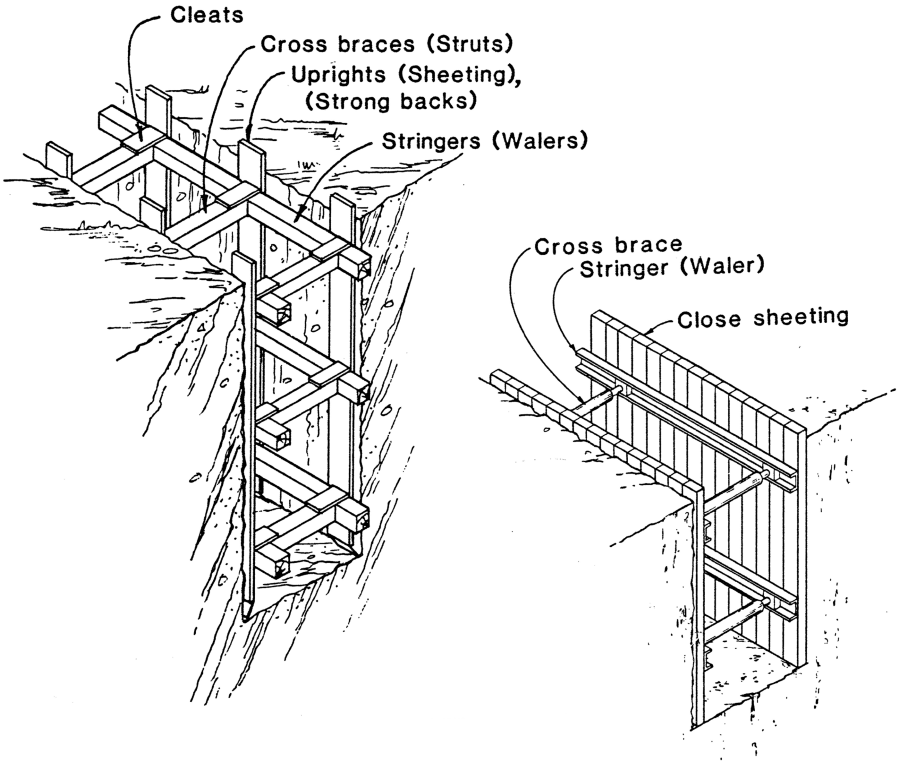


Figure 10-9. Examples of trench shoring and the components involved.

The strength of the beam material, the kind of loading, the beam length and other factors determine the size of load that a beam can carry. Bending or deflection can create hazards even before total failure occurs. For example, a flat roof that deflects can cause water to accumulate or pond and accelerate failure. The more water that accumulates, the more the roof deflects. This cycle could lead to collapse. Ice, leaves, and debris around roof drain inlets can lead to water buildup.

As a beam bends, part of its cross-section is in compression, part in tension. Figure 10-12 is a diagram of the stress distribution. The *neutral axis* is the location in the cross-section where stress is zero.

Properties of a beam cross-section influence the load it can carried. One property is the *moment of inertia* I. The

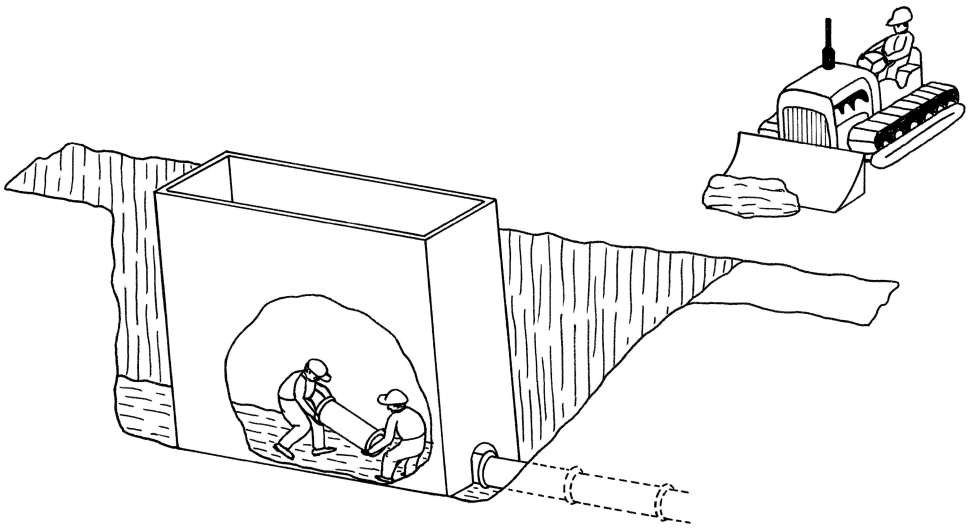


Figure 10-10. A trench shield in use.

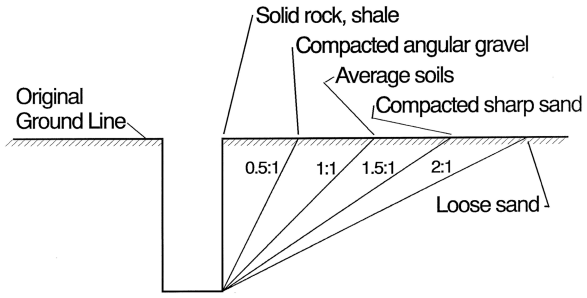


Figure 10-11. Typical angles of repose for various soils.

moment of inertia is the sum of differential areas multiplied by the square of the distance from a reference plane (often the neutral axis) to each differential area. Because the formula squares the distance, the strength of a beam increases rapidly as its cross-section extends farther from the neutral axis.

A rectangular beam will be much stronger when loaded along its thin dimension than along its flat dimension. An example is a 2 in by 8 in piece of lumber. When lying flat, a load on the 2 in dimension causes a lot of bending. When the board is vertical, the same load causes very little bending.

Another property used in beam load computations is the *section modulus* Z. It is the moment of inertia divided by the distance from the neutral axis to the far edge of the beam cross-section.

The maximum bending stress s_b in a beam under a bending or flexural load is:

$$s_b = Mc/I = M/Z \qquad (10\text{-}10)$$

where

M = the maximum moment created on the beam by the load

c = the distance from the neutral axis to the farthest element of the beam

I = moment of inertia

Z = section modulus

A problem faced by a designer is to minimize the size and cost of a beam while providing a safe load capacity. Similar to the procedures for evaluating other stresses, designers must compare a computed load or stress to an allowable load or stress. Similar to other materials, allowable loads differ from maximum loads that produce failure by some appropriate factor of safety. Designers select beams from standard types, materials, and shapes. Engineering design tables provide data about section properties and other beams characteristics.

The deflection exhibited by a beam under load is a function of material, section properties, length, means of support or attachment and loading. Engineering tables give design formulas for maximum deflections and slopes created by loads.

Floors

Determining the safe load on a floor is a common structural issue in safety. Loads sit on a floor and transfer forces to supporting joists. The joists transfer loads to where it is supported at a wall or to beams. Figure 10-13 illustrates a typical assembly for a floor in a building.

Designers find allowable floor loads in handbooks or building codes. The design task is providing an economical, attractive, and functional floor system that will safely carry expected loads. There are usually two load components. *Dead loads* include the weight of the building and its components. *Live loads* are the loads placed on the floor by users. One would expect different live loads for a warehouse, an office, and a parking garage. In an office, occupants may distribute file cabinets among work areas or concentrate them in one location. A designer must consider such use conditions in a floor design. Some building codes require posting of floor loads used in a design, at least in certain kinds of buildings.

Example 10-7 A floor has a uniformly distributed load of 150 lb/ft^2. Floor joists are 18 ft long and spaced 2 ft on center. What is the load on one joist? Ignore dead loads. If each end of each joist rests on a beam, what load does each joist transfer to a beam on each of its ends?

This example focuses on each individual joint and its supporting beam to make the analysis simpler for each beam.

The floor area acting on each joist is $2\text{ ft} \times 18\text{ ft} = 36\text{ ft}^2$. The total load on one joist is $36\text{ ft}^2 \times 150\text{ lb/ft}^2 = 5400\text{ lb}$, evenly distributed over its length. The load transferred to a beam on each end is half the total load, $5400/2 = 2700\text{ lb}$.

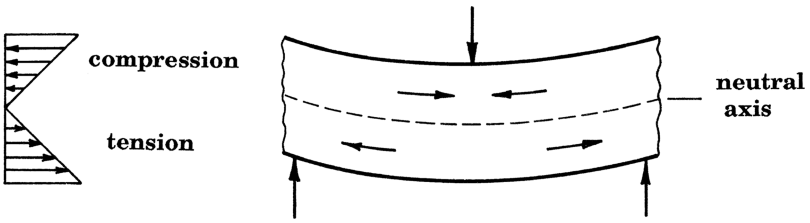


Figure 10-12. Distribution of stress in a beam cross section during bending.

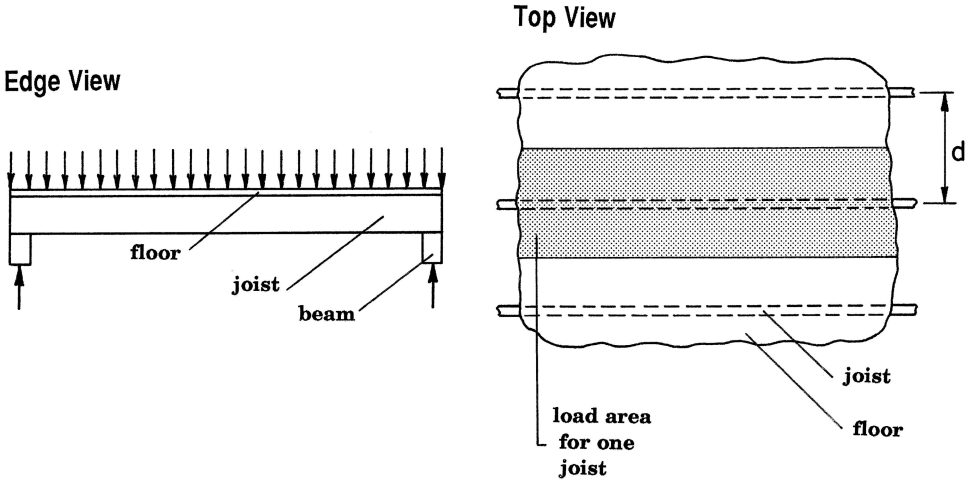


Figure 10-13. Typical structural components and load distribution for a floor.

Columns

By definition for structures, columns are structural members loaded in compression that have an unsupported length at least 10 times greater than the smallest lateral dimension. There are long and intermediate columns. The definitions reflect how length affects failure. Long columns fail by buckling or excessive lateral bending. Intermediate columns fail by a combination of crushing and buckling.

For a long column the critical load is the maximum allowable axial load (acting in the direction of its length) while remaining straight. At the point of critical loading, a long column becomes unstable and will bow easily if there is a slight lateral load along its length. At greater axial loads, the column will buckle without a lateral load. The equation for computing the critical load P is:

$$P = NEI\pi^2/L^2 \qquad (10\text{-}11)$$

where

N = an adjustment factor for end conditions

E = the modulus of elasticity for the material

I = the moment of inertia

L = the length of the column

For fixed ends, N = 4. For one end fixed and the other hinged, N = 2. When both ends are hinged, N = 1. When one end is fixed and the other is free, N = 1/4. I is the smallest moment of inertia for the column cross section. Equation (10-11) is *Euler's formula for long columns*. Some call it the *Euler Equation*.

Multiple Modes of Failure

For each assembly of structural components, there are several ways it can fail. A designer must analyze the assembly and identify all modes of failure. A designer must analyze all modes of failure to determine which is most likely to occur. Even very simple structures become complex during proper design.

Consider a simple, common structural case, anchoring a shelf to a wall using brackets and screws. Assume there is one screw near the top of each bracket and one near the bottom (see Figure 10-14). The shelf must support some books. It may also have to support a child hanging from it, given the use environment in a home recreation room. Both are foreseeable conditions. A design must consider both. This simple structure has several possible modes of failure:

- The two anchoring screws could fail in shear at the wall-bracket interface.
- The screw at the top of a bracket could fail in tension and pull out of the wall. The load on the shelf tends to rotate the bracket and pull the top screw away from the wall.
- The bracket material could fail as the head of the top screw creates a shear load on the material.
- The bracket could cause a similar shear failure on the head of the screw.
- The lower end of the bracket, which is in compression, could crush the wall material.
- The bracket could bend, because the top leg under the shelf is, in essence, a cantilevered beam.
- The threads on the screws could cause shear failure in the wall material.

Any of these modes of failure could occur. In a comprehensive evaluation a designer will need to analyze all possible failure modes to determine which will occur first. The designer's evaluation may not include all possible modes of failure, since an installer can add variables to the case.

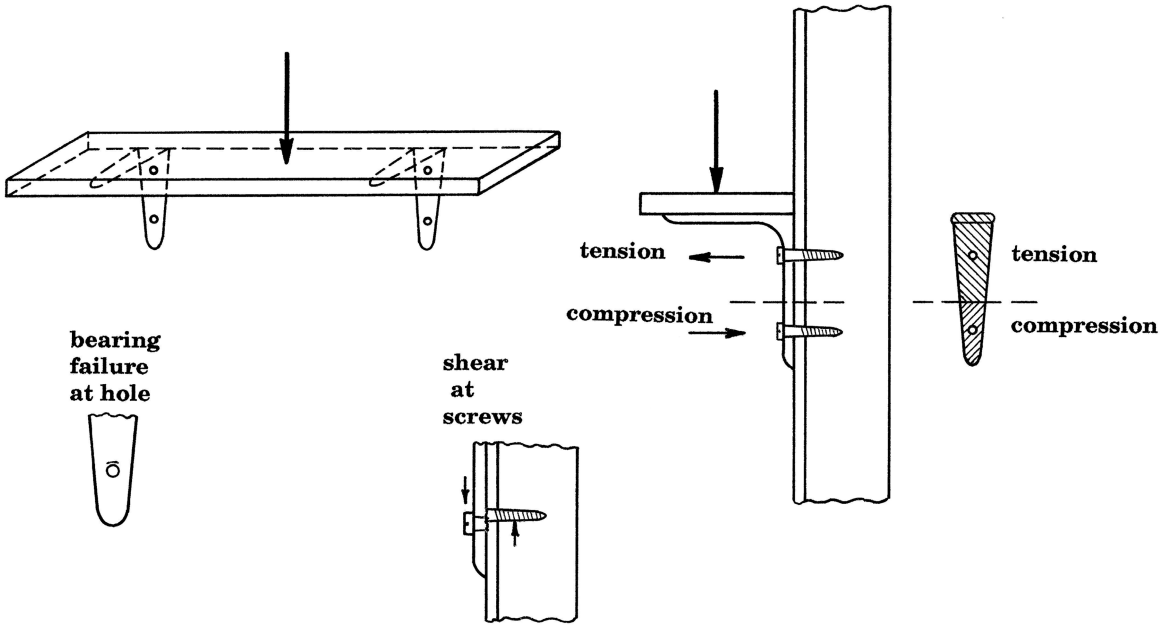


Figure 10-14. A shelf supported by brackets attached to a wall. The load tends to rotate and place tension on the upper screw and compression on the lower end of the brackets. The brackets could compress against the wall at the lower ends and damage the wall. The weight could also cause a shear failure for one or more screws.

EXERCISES

1. When using a water slide several youth piled up in one section to form as long a human chain as possible. In doing so, they overloaded the joint between sections causing the joint to fail. The 12 young people fell about 40 ft to the ground.

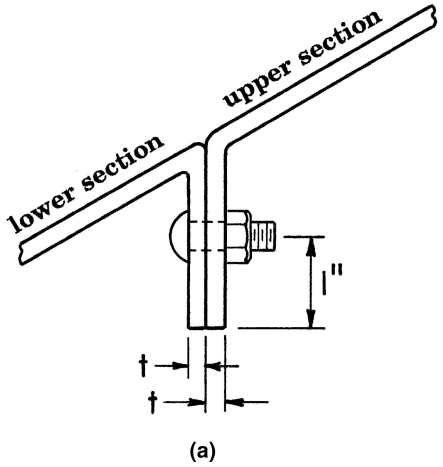
This exercise includes two possible designs for the connection between sections of the slide. In each case the joint has three bolts connecting the two sections (upper and lower) together. Assume the three bolts carry the entire load at the joint.

In the first design (see figure labeled Exercise 10-1a), a shear load is on the connecting bolts.

In the second design (see figure labeled Exercise 10-1b), a tension load is on the bolts when the lower section carries a load. When the upper section carries a load, the end of the upper section rests on the lower section.

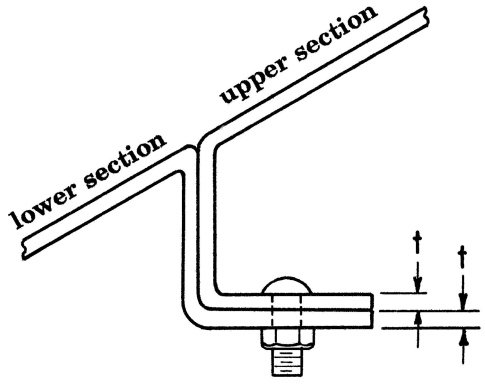
Estimate what force F acting on one side of the joint (assume the other side or section is rigidly supported) will cause failure when using the design data at the end of the exercise and the mode of failure is:

(a) bolt shear for first design (see figure labeled Exercise 10-1c)



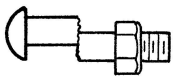
(a)

Exercise 10-1a. Design (1) for Exercise 10-1.



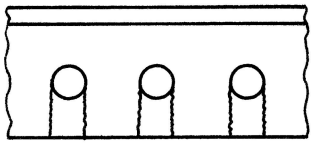
(b)

Exercise 10-1b. Design (2) for Exercise 10-1.



(c)

Exercise 10-1c. Bolt shear diagram (a) for Exercise 10-1.



(d)

Exercise 10-1d. Plate shear diagram (b) for Exercise 10-1.

(b) plate shear in the upper section for the first design when the slide users placed a load on the lower section (see figure labeled Exercise 10-1d)

(c) bolt tension failure for second design

Data:

Factor of safety = 3
Bolts are 1/2in.diameter
Breaking tensile stress =45,000 lb/in.^{2} (bolts and plates)
Breaking shear stress = 62,000 lb/in.^{2} (bolts and plates)
Holes are1/2 in. diameter
Plates are1/10 in. thick
Breaking shear stress = 40, 000 lb/in.^{2}(bolts and plates)

2. Joists support a floor and transfer their load to beams at each end of each joist. Refer to Figure 10-13. Joists are 2 ft on center and 30 ft long.

(a) If w, the load on the floor, is uniformly distributed and is 30 lb/ft^2, what is the load on one joist?

(b) If the maximum flexural stress S in a joist is given by S = M/Z, where M is the maximum bending moment (pound-foot) and Z is the section modulus (cubic inches), what is the stress in a joist that has a section modulus of 50 in.^{3} and is 30 ft long? Assume that the maximum bending moment for a simply loaded joist is given by $M = wL^2/8$,

(c) If the joists are made of pine, which has an allowable bending stress of 9,300 lb/in.^{2}, will it carry the load?

3. An office decided to centralize its paper files. All the file cabinets in one department will sit in a row. The file cabinets sit over a floor joist. The cabinets are positioned perpendicular to the joist with the centers based on depth directly over the joist. Each file cabinet is 18 in. wide by 30 in. deep and weighs 300 lb. Determine:

(a) the total load on the one joist (neglect the weight of the floor itself)

(b) the load transferred to the beam located at each end of the joist (assume the cabinets are centered on the joist length)

(c) the maximum bending moment in the joist

(d) the maximum flexural stress in the joist

4. A contractor will dig a trench in Type B soil to a depth of 13 feet. It will be five feet wide. Identify acceptable arrangements for timber shoring from Table 10-2.

5. A home swimming pool recirculates the water in the pool through a filter system. A pump moves the water from the drain(s) in the bottom or sides of the pool through filters and returns it to the pool. It is known from experience that children will sit on the single drain port in some designs after someone removes the drain cover and does not replace the cover. There are incident reports that the children in some of these cases had their intestines sucked into the recirculation system causing serious medical problems for them.

Consider design options for reducing or eliminating the hazard of injury to body parts caused by the suction at the drain port(s) for pool recirculation systems.

(a) What is the likelihood of occurrence and the severity of potential injury for each option?

(b) What legal cases have resulted from various recirculation designs for pools as found in cases on record?

6. Select a product. Analyze one or more structural components and identify modes of failure for each component.

7. Locate one or more articles on a significant earthquake event and identify the causes of failure for structures that resulted. Identify what changes in designs resulted from a study of the effects or could reduce the degree of damage in one or more of the damaged structures.

REVIEW QUESTIONS

1. Define the following:

(a) tensile force

(b) compression force

(c) shear force

(d) torsional force

(e) bending force

(f) bearing force

2. Explain the concept of a structural safety factor.

3. Why is a safety factor used in structural analysis?

4. Why should a table of material strength or load capacity have a factor of safety incorporated into it?

5. Why should a field table have a factor of safety incorporated into it?
6. What motions from an earthquake potentially cause buildings and other structures to fail?
7. What is a tsunami? How is one initiated? How does it cause damage?
8. Name eight possible modes of failure for structures.
9. Name five causes for structural failure and give an example of each.
10. Give an example of an application for safety of each of the following areas of mechanics:
    (a) static mechanics
    (b) dynamics
    (c) friction
    (d) fluids or hydraulics
    (e) soils
    (f) strength of beams
    (g) strength of columns

NOTES

1 "Rocking That Fatigued Bolts Felled Arena Roof," *Engineering News Record*, August 16, 1979, pp. 10–12.

2 "Design Flaws Collapsed Steel Space Frame Roof," *Engineering News Record*, April 6, 1978, pp. 10–12.

3 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10933

4 29 CFR 1926 Subpart P Appendix B, Sloping and Benching (https://www.osha.gov/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10932)

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CHAPTER 11

WALKING AND WORKING SURFACES

11-1 INTRODUCTION

The surfaces and devices on which people stand, walk, work, and climb contribute to many accidents, injuries, and deaths. They incur significant costs. Falls result in 20% of all accidental deaths. Slips and falls are the leading cause of accidents and deaths in the home. A study of Californian worker compensation claims found that work surfaces are the most common agent for job-related injuries (21%). Falling objects also cause many on-the-job injuries.[1]

According to NIOSH, falls from elevations are the fourth leading cause and account for 10% of occupational deaths. NIOSH studied 90 worker deaths from falls for a range of job settings, involving a variety of work equipment and conditions. The study offers recommendations for preventing such deaths.[2]

A study of 289 construction worker falls in Qatar showed 29 deaths (8.6%); 97% of the workers were male immigrants, and the mean medical cost was US$16,000.[3]

There are public, business, construction, assembly and other walking and standing surfaces made of a wide range of materials. The surfaces vary in slip resistance. The surfaces may have railings to prevent falls to levels below or provide users a place to grasp. Irregularities and placement of items may lead to tripping and falls.

This chapter will review some of the surfaces, equipment, and features that lead to and prevent falls and related injuries and death.

11-2 TRIPPING AND SLIPPING

Tripping

Most everyone has caught the toe of their shoe on a protruding or irregular surface of a floor, carpet or sidewalk. Tripping is interrupting the motion of the foot during a step. A fall results if there is a enough interruption of someone's gait. In tripping, a fall is forward because one cannot place the foot as normally expected while the momentum of the body continues forward.

Hazards Many conditions lead to tripping. There are surfaces irregularities. A change in surface elevation of one-eighth inch or more can lead to tripping. Objects protruding from the floor or the walking surface can cause tripping. Warped floor boards, a missing floor tile, an uneven tile or brick, carpet edges, loose carpet or rugs, protruding nails and screws and chipped and cracked concrete are all examples of irregular surfaces or protruding objects. Tripping may result from simply leaving objects lying where someone walks. Common examples are electrical cords, pipes, boards, and toys. Objects protruding into a walking zone from the side and near the floor create tripping hazards. The more the objects protrude into the walking zone, the greater the risk of tripping. Examples are items sticking out from storage racks at or near the floor.

People do not always see tripping hazards. A planned evaluation of surfaces can help identify tripping hazards effectively. While walking or performing standing tasks, people do not always watch the detailed condition of the floor or surface they are walking or standing on. The normal line of sight is about 10 to 15 degrees below horizontal relative to the eyes. People look ahead when walking normally. Most of the time people do not walk around looking down at their feet. As a result, people do not usually see small changes in surface elevation. In addition, people do not always perceive surface irregularities. Studies have shown that color, texture, low light levels, and glare may obscure changes in walking surfaces.

In addition, some people have walking difficulties and are unstable. Some may have vision difficulties and not observe a change in surface conditions. They may be wearing clothes or shoes that catch on something rather easily. They may not see beyond items that obstruct their vision, especially if carrying large objects.

Not all tripping incidents result in falls and not all falls lead to serious injury. Surrounding objects or conditions may contribute to the severity of tripping incidents. On an elevated surface tripping may lead to a long fall. Even on a flat surface, the fall may be against a protruding object or one may land in a manner that causes serious injury.

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CASE 11-1

11-1a

August 2, 2013. Formwork for a concrete column began to leak as concrete pouring occurred on the sixth floor of a building under construction. A worker tried to fix the leaking form, lost his balance and fell over the edge of the building. Paramedics pronounced the worker dead on the scene.

11.1b

May 30, 2014. Workers were dismantling concrete forms on the fifth floor of a building under construction. A piece of the formwork lumber fell. It struck the head of a worker engaged in a different operation at the ground level of the construction site. The worker died from the impact.

Controls Preventing tripping starts with observation of walking and working surfaces. Also, good housekeeping can prevent many tripping hazards. Housekeeping involves picking up tools, scrap, and waste. It includes properly positioning or storing objects like pipes, lumber, pallets and file drawers or other objects that protrude into the walking zone. The intersection of different floor finishes, such as the interface of tile and carpet, should be at the same level. Designs should eliminate elevation changes. For example, building designs should avoid elevation changes, especially small and unusual ones. People do not always see one or two step changes in elevation.

Inspection and maintenance can help remove tripping hazards. Remove protruding nails and screws or set them even with the floor surface. Repair damaged tiles, floor boards or carpet. Remove unnecessary mats, electrical cords or similar objects that extend across walking zones. If there are temporary electrical or communication cables across a walking zone, tape them to the floor. Use other protections to prevent tripping on them. Route them overhead if possible.

It is often hard to see changes in elevation. One way to improve visibility is to make different levels different colors. Avoid textured patterns that hide changes in elevation. Changes in surface levels should have good lighting. Warning signs may alert people to tripping hazards. Also, avoid sources of direct or reflected glare that can interfere with the ability to see changes in elevations.

Slipping

A slip is the sliding of one or both feet on a surface. If a person slips unexpectedly, there is a good chance that the slip will result in a fall. Even without a fall, a slip can cause strains to muscles and joints. In a fall resulting from a slip, the foot or feet usually slide forward and out from under the body, producing an unstable condition.

When walking, people expect to experience a certain resistance between the floor and their shoes or feet. If the resistance is less than expected or the resistance diminishes suddenly, a slip will probably result. A slip occurs when the lateral force applied at the foot-surface interface is greater than the frictional resistance available. Although this principle seems simple, there are continually changing forces during walking. That complicates many walking situations. To a great extent the possible resistance is a function of the combination of shoe and flooring materials at their interface. Differences between static and dynamic friction coefficients further complicate the resistance possible. Activity and gait or walking style affect the force created at the shoe–floor interface. Examples are wet, dry or oily surface conditions and foreign materials like sand or food spills. The amount of polish and other floor conditions can change the resistance. Sloping surfaces add to horizontal forces and may increase the likelihood of slipping.

It is difficult to predict when a slip will occur. However, activities like pushing, pulling, accelerating, turning corners and throwing will produce higher horizontal forces at the foot-surface interface than normal walking. Also, horizontal forces increase as the angle formed by the leg with vertical increases. When people know that a surface is slippery, they will walk with a short stride to prevent slipping.

Measurement of Floor and Shoe Slipperiness Tribology involves the study of friction, lubrication, and wear. Slipperiness is part of tribology. Tribometry is the measurement of friction and slipperiness. Measurement of slipperiness of shoes, floors, tires, pavements, and other applications involve tribometry instruments.

There are several methods for measuring floor slipperiness. Typically, each produces a reading on a scale from 0 to 1. Different devices produce different resulting values. Various devices have been in vogue over the years and their validity in mimicking the human gait varies.

One type, a slip meter, is a small, portable instrument that a user pulls along the floor. It measures horizontal force. A dial gives a reading of force created by the device on the string used to pull it. There are several commercial brands of slip meters.

Another type of slipperiness testing device is a swinging pendulum. It gives a reading of drag. A plate composed of

a prescribed material (such as that of a shoe) is set at the end of the swinging pendulum. The plate slides for a short time across a surface during the pendulum swing. The instrument measures the resistance or drag. The NBS-Sigler pendulum impact tester and the British pendulum tester use the pendulum principle.

A third type of slipperiness measuring device is an articulating arm device. It is usually a bench-top instrument that places a load on prepared samples of shoe material and floor material. A static load starts directly over the sample. A hinged bar holds the load above the material sample at the other end. The machine moves the load slowly to one side of vertical. The bar begins to form an angle from vertical. The machine increases the angle of offset until the shoe sample pad slides against the floor sample. Two machines of this type are the James machine and the NBS-Brungraber slip-resistance tester. There is also a portable version of the NBS-Brungraber slip-resistance tester.

The tests and the testing devices for flooring and floor–shoe interfaces continue to evolve. That leads to new testing devices, methods and standards. However, not all countries agree on the use of the same procedures.

Some measurement standards suggest that a criterion of 0.5 defines whether a shoe-floor combination is safe. Higher values are defined as slip-resistant; lower values are slippery. However, it is difficult to relate a reading from one of these instruments to a qualitative description of slippery or whether a surface is safe. It is also difficult to relate test values to actual conditions or to predict when someone will slip. For example, a real floor may have wax buildup, small amounts of sand, mud, water, oil or other material present or be highly polished. Such conditions are difficult to incorporate into test procedures. Specially prepared test specimens may not fully replicate actual shoe–floor conditions. Test data provide valuable information for design and material and finish selection. Data may not determine why a slip occurred or accurately predict when a slip will occur.

One should note that testing of floor surfaces provides an index for estimating the likelihood of someone slipping. Testing cannot assess all of the variables involved to predict actual slips. A slip resistance test result cannot determine whether a material is fully safe for use.

The National Floor Safety Institute (NFSI)[4] has members from various business interests, such as insurance, flooring manufacturers, finishing manufacturers, various industries and other sponsoring groups. NFSI provides guidelines for achieving floor safety. It offers test methods and related literature.

Hazards One hazard related to slips is having a combination of shoe and floor materials and floor finish that may cause slipping. Polished shoe and floor materials are more likely to be slippery than rough ones. Repeated mopping of some floor materials may increase slipperiness. The pores of the flooring material, such as ceramic tile, which originally were slip-resistant, can become filled with oily material after the substances that have been dissolved by the detergent and the water dry.

Another hazard is a sudden change in floor conditions. For example, when one moves from a dry surface to one that is wet, muddy, icy, or oily, there is an increased chance for slipping. Adjusting one's gait can reduce the potential for slipping or falling. A sloping surface can add to a slip hazard.

A rapid change from a slippery surface to a high friction surface can be hazardous. In this situation, people may stumble, rather than slip. In a stumbling fall, the foot encountering a high friction surface may lock and not move or pivot as expected. With the rapid change in surface conditions, a person's body moves faster than the feet and creates an unstable condition.

Controls One control for preventing slipping conditions involves inspection. Work planning should include inspection of working and walking surfaces to remove or prevent slip hazards.

One control for preventing slips is housekeeping. As much as possible, walking and working surfaces must be free of foreign materials that can result in slipping. Pick up or wipe up water, mud, snow, ice, oil, grease, loose materials, scrap, and waste. In some cases, planning can prevent oversprays and other foreign material from getting on walking and standing surfaces. In retail buildings, spills and dropped items require quick attention from employees to prevent falls by customers or other employees. Flooring suppliers may offer recommendations on cleaning procedures and materials to minimize slippery surfaces.

In areas involving wet processes, there should be drains that reduce standing liquid. In certain situations, raised floor surfaces may be an option so workers do not have to stand in accumulated wet, oily or scrap material. As a temporary solution, use of absorbent materials may aid when cleaning up spilled oils.

Where a change in surface conditions occurs, there should be warnings. For example, during mopping activities workers should mark wet areas with warning signs. Procedures like mopping half the width of a hall at a time may help so people do not have to walk through a wet area. At locations where people track in ice, snow or water or other materials, warnings can help. Mats and rugs can also help reduce hazards for such conditions by providing a transition zone and reducing tracking of foreign materials. However, avoid using protective runners that become slippery when wet. If there is heavy tracking, continual cleanup is essential.

Another control is selection of shoe and surface materials and floor finishes. Employers should help employees select appropriate footwear for their jobs. Purchasers should avoid shoe materials that are slippery when either dry or wet.

There is a wide range of flooring materials that designers can select. Many manufacturers have slip test data for their flooring and surface products. Technical references may contain representative data on the slipperiness properties of various materials. Designers should avoid sudden changes in slip resistance properties in flooring, stairs, and other walking and working surfaces.

Also important are the selection, application, and maintenance of surface treatments and finishes. Many manufacturers and suppliers have test data on floor finish products. Independent testing and evaluation of samples may be worthwhile before the final selection. To reduce slipperiness, consider adding abrasive strips in strategic places, such as on stair nosing or wet areas. Fine silica sand mixed into flooring paints can reduce slipperiness. Apply and maintain waxes and other finish materials properly, since maintenance procedures can affect their slip properties. For example, excessive buildup of finish material or excessive buffing can alter slip properties from those obtained in test conditions. Locations where slip hazards are high may need different materials and finishes than other locations.

11-3 FALLS

Falls often cause injury. They may result from slipping, tripping, stumbling, and imbalance. They include falling from one surface to another or on the same surface where standing or walking occurs.[5] Falls include falling objects that may strike people or objects below.

Physics

In a moment of humor people say, "It's not the fall that is so bad, it's the sudden stop when you hit the ground." One must understand the physics of falls in order to understand the potential severity. Understanding physics and some physiology will also help one understand design features and how to reduce hazards through effective controls. Three important aspects of falls are: (a) the motion and height of a falling body; (b) the impact as a fall stops; and (c) the ability to withstand impact.

Motion and Height of Falls One characteristic of a fall is how far a body moves vertically during the fall, i.e., the height. By knowing the distance that an object falls, s, one can compute the velocity, v, at any point in the fall:

$$v = (v_o^2 + 2gs)^{1/2} \tag{11-1}$$

where

v_o = the initial velocity (zero in most cases)

g = the acceleration of gravity

In addition, if one knows the weight of a body, W, one can compute the kinetic energy, KE, at the point where the body reaches a velocity v:

$$KE = mv^2/2 = Wv^2/2g \tag{11-2}$$

One can estimate the KE at any point in a fall by combining Equations (11-1) and (11-2).

Impact When one body strikes another, the two bodies absorb much or all of the stored energy. The deformation of the two bodies is how they absorb the energy. The two objects may not deform equally. If the bodies do not absorb all of the energy by deformation, the remaining energy transfers into additional motion of the bodies. Very often a falling object strikes the earth, a floor or other structure that does not deform or deforms very little. A slow-motion video of a baseball bat striking a baseball illustrates the impacting objects.[6]

The injuries that result from a fall of a person onto a surface are, in part, a function of the rate of deceleration. From an estimate of the stopping distance (the distance the center of mass moves after initial impact), one can determine the rate of deceleration, a:

$$a = V^2/2s \tag{11-3}$$

where

V = the velocity at the point of impact

s = the stopping distance

Some surfaces are hard and massive and do not deflect or deflect very little.

Often one compares the rate of deceleration to the acceleration of gravity, G. The number of Gs is determined from:

$$G = V^2/2gs = a/g \tag{11-4}$$

Another important factor affecting the severity of injury is the contact area, A, between two impacting bodies. The force of a falling object striking a body over a large area will produce a less severe injury compared to the same force applied to a small area. For example, falling onto a trampoline mat or mattress cushions a fall and is not likely to cause an injury. The mattress absorbs a lot of energy and distributes the force over a large area. Falling onto a pointed object or sharp edge is more likely to cause injury than falling onto a flat object or rounded edge. In general, a similar relationship exists for a person landing following a fall.

The force of impact, F_i, is:

$$F_i = Wa/g \tag{11-5}$$

The material against which the force acts will resist this force. The material may be human tissue. The ability of the material to withstand the impact force can be

determined from:

$$F = sA \tag{11-6}$$

where

s = the stress in the material

A = the area over which the force is applied

One must compare the applied stress to the tensile, compression, shear or bending stress the material can withstand. Data tables provide information about the stresses that materials, including human tissues, can withstand.

Injury to tissues other than those receiving the initial impact occur because the force of impact transfers to other elements of the body, such as muscles, ligaments, bones, joints, or organs.

Impact Limits of the Human Body

Data about the strength properties of human tissue and structures often come from cadaver or animal studies. The data help in estimating the likelihood of injury or severe injury in some situations. The data may help in reconstructing certain accidents and considering the kind and extent of tissue damage. However, because the body and actual conditions of an accident are complex, it is difficult to use analyses to describe exactly what happened or what caused the resulting injuries. Injury analysis and autopsies by forensic physicians may identify conditions which can produce certain kinds of injuries. Figure 11-1 provides some data about human tolerance to impacts.

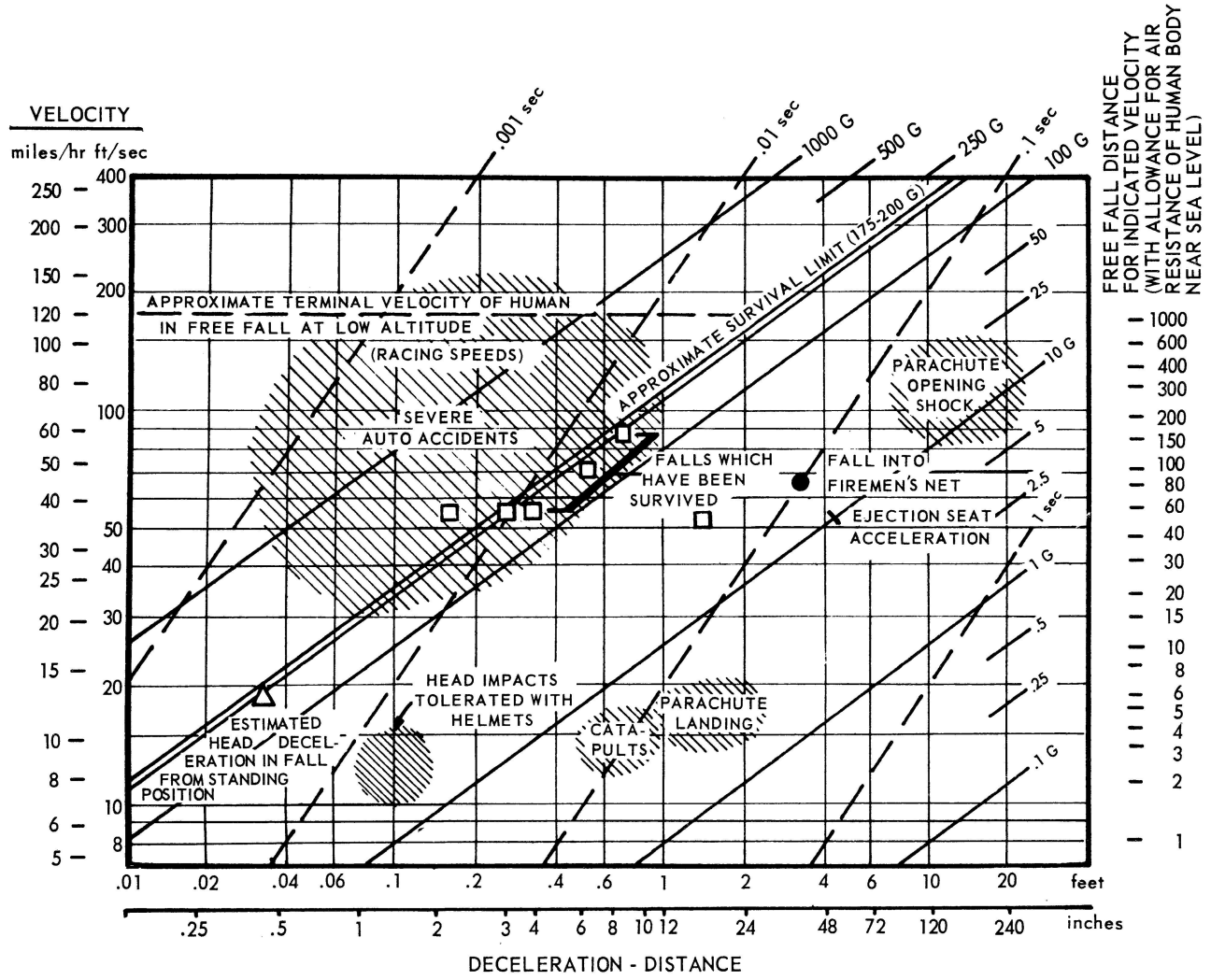


Figure 11-1. The effects of human impacts from falls. (From P. Webb, *Bioastronautics Data Book*, NASA SP3006, Washington, DC, 1964.)

11-4 PREVENTING FALLS AND INJURIES

There are four goals in fall protection:

- Prevent people from falling.
- Prevent objects from falling.
- Reduce energy levels if falls do occur.
- Reduce injury at impact.

By meeting the first two goals, the latter two are unnecessary. The following text discusses these goals, which Table 11-1 summarizes. The references provide extensive details on fall protection methods and equipment. Individual countries have their own fall protection standards. For example, OSHA standards apply to workers in the United States. The United Kingdom has its own standards,[7] and Australia has different standards.[8]

Preventing People from Falling

Remove Slipping and Tripping Hazards The preceding text discussed controls for slipping and tripping hazards and these apply to any surface where people may be present.

Warnings and Barriers Particularly where there are changes in level between surfaces, there should be warnings and barriers. A barrier is a restraint that will prevent a fall from an upper to a lower level. It must withstand the force of people running into it, leaning on it or sometimes standing on it. Common barriers are guardrails, covers over openings, and cages on fixed ladders. OSHA requires that these devices withstand a load of 200 lb at any point. Because the weight of many people exceeds this value, higher design loads may apply. Designs for covers over openings should not introduce tripping hazards.

Covers over openings should be anchored in place or, if they are temporary, have warnings on them to indicate their purpose. It is not uncommon to have a sheet of plywood covering an opening in a roof or floor during construction. It is also not unusual to have two people pick up the plywood sheet to remove it and have the person carrying the rear of the sheet fall through the opening.

A barricade placed around a temporary excavation and a rope placed around the perimeter of elevated floors during building construction are warning devices. Most warning devices do not fully restrain someone. Flags and bright colors make warnings easier to see. Visual and auditory signals, such as flashing lights and beepers, help people recognize warning devices.

The Standard Guardrail A commonly specified barrier is the standard guardrail illustrated in Figure 11-2. It has vertical supports, typically spaced 10 ft or less apart. It has three horizontal parts: top rail, middle rail, and toe board. Infill between these parts is important as well.

The function of the top rail is to prevent someone from falling over it. The height of a top rail defines its effectiveness. The height should be at least 42 in. from a floor. A shorter dimension will protect fewer people. A higher railing will protect the very tall people also. OSHA requires a 42 in. height.[9]

Consider the mechanics of someone falling or simply leaning against a horizontal rail. We know that the center of gravity for a human body is about 3 in. above the midpoint of one's height. If the center of gravity acts above the rail, a

TABLE 11-1 Summary of Fall Protection Methods

Objective	Method
A. Risk Assessment	1. If possible, review the surface conditions and equipment in advance of their use 2. Make sure people wear proper clothing and shoes
B. Prevent falls of people	1. Remove tripping and slipping hazards 2. Protect edges and openings a. Provide barriers (guardrails, covers, cage, etc.) b. Proved visual and auditory warnings 3. Provide grab bars, handrails and handholds 4. Provide fall-limiting equipment
C. Prevent objects from falling on people	1. Housekeeping (remove objects that could fall) 2. Barrier (toe boards, guardrail, infill, covers, etc.) 3. Proper stacking and placement 4. Fall zone 5. Overhead protection
D. Reduce energy levels	1. Reduce fall distances 2. Reduce weight of falling objects
E. Reduce injuries from falls and impact	1. Increase area of impact force 2. Increase energy absorption distance

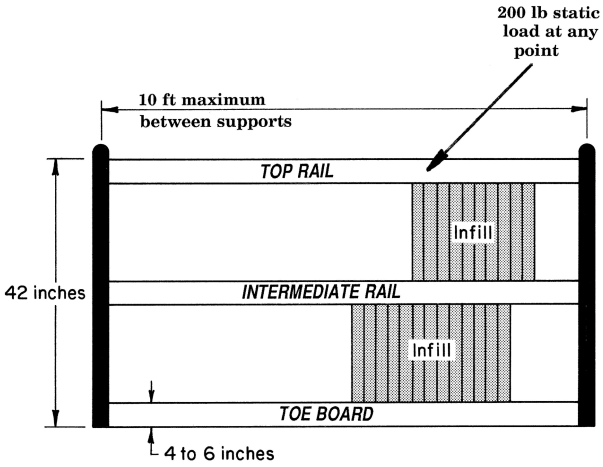


Figure 11-2. Features of the standard guardrail.

person falling against the rail would rotate over the top of the rail. If it acts below the rail, a body would rotate under the rail. For a person 6 ft tall, the center of gravity acts at a height of about 39 in. (72/2 +3). Therefore, if 99% of the population is less than 6 ft 6 in. tall, a 42 in. high top rail will prevent rotation over the rail for all but very few people. Using this estimate method, a 45 in. railing would protect people who are 7 feet tall.

The middle rail will keep someone from falling when their body rotates under the top rail. As a precaution for children, infill may be needed. It also prevents people and objects shorter than the top rail from falling through the opening under the top rail.

A toe board is normally a 4-6 in. high barrier along the walking surface. Its has two purposes. It prevents someone from placing their foot over the edge of an elevated surface. Also it prevents objects from sliding or rolling over the edge and falling on someone below.

Infill also prevents objects from falling from an elevated surface. The size of objects that could fall between the rails and toe board determines the size of the opening in infill material. For architectural handrails, the space between balusters should be small enough to prevent children from falling through the openings or getting their heads caught.

Sports Facility Guard Rails Places of assembly for the public create some unique situations related to walking and related surfaces. In particular, sports facilities may create unique design challenges. For example, people can fall from temporary, permanent or roll-away bleacher seats or stairs. There are some standards applicable to such equipment.[10]

There is often a design tradeoff between visibility at a sports events and fall protection for those in the front row of elevated seating areas. People have fallen from elevated seating areas resulting in serious injuries and death. Protective railings for the first row of seating are lower than other locations not involving a seated view of the events. There have been various attempts to solve these issues through use of see-through glass or clear plastic panels above the short guard rails.

Handholds When people move up or down between two different levels, it is important to provide a capability for three-point support. That means having two hands and one foot or two feet and one hand supporting the activity. Steps or ladder rungs provide support points for the feet and grab bars, handrails and handholds provide support for the hands. During climbing activities there are times people must reposition a foot or hand to a new support point. Should the foot in contact slip, the only way to prevent a fall is with a firm grip with the hands. Handholds must be available at all points of climbing until a person is standing firmly with both feet on the new upper or lower level.

CASE 11-2

11-2a

Arlington, Texas, July 8, 2011. Father and firefighter, Shannon Stone, age 36 and who stands 6 foot 3 inches, took his 6-year-old son to the Texas Rangers baseball game. They sat in the first row of left field. They were close to their favorite player, left fielder and the current American League Most Valuable Player, Josh Hamilton. They wore jerseys with his player number. On the way to the ball game they even stopped and purchased a new glove in hopes of catching a baseball.

During the game, Hamilton chased down a foul ball that ended in the corner of left field. He tossed it into the stands and Shannon Stone caught it. In doing so, he fell over the 33-inch-high railing and 20 feet down to concrete below. Mr. Shannon rode an ambulance to the hospital and soon died.

11-2b

A year earlier, in a similar accident on July 6, 2010, at the same stadium, another firefighter and fan, Tyler Morris, fell 30 feet from the second deck in right field trying to catch a foul ball. He survived a fractured skull and a broken ankle when he landed on seats below.

CASE 11-3

May 4, 2014, Providence, RI. The Ringling Brothers and Barnum & Baily Circus mid-day performance was close to completion around 1:30 p.m. at the Dunkin' Donuts Center. A highlight was the "Hair Hang Act." Eight performers hung from a circular frame appearing like a human chandelier. As the frame rose to about 25 feet, the entire frame assembly suddenly fell to the circus floor taking the eight performers with it. The audience was shocked. All eight performers received injuries along with a circus employee on the floor. Many had broken bones.

An OSHA investigation resulted in a $7,000 fine, the maximum allowed by law. The report established that the connecting ring, called a carabiner, supporting the circular frame failed from improper loading and failure to follow manufacturer's instructions. (A carabiner is a hook-like device with a spring-loaded mouth.)[a,b]

[a]www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=26943
[b]http://abcnews.go.com/US/wireStory/feds-propose-7k-fine-circus-hair-hanging-stunt-26677655

There should be enough space in handholds or behind handrails and grab bars for fingers, even when wearing gloves. The cross-sectional shape of a handrail or handhold should permit near maximum grip strength. That occurs when someone curls the fingers fully around the device. Handholds should be strong enough to carry a person's weight. The Department of Transportation has specifications for access to the rear of trucks and truck trailers.[11] and several OSHA regulations address grab bars and handholds.[12]

An important design consideration for handholds, particularly those that extend along lengths of ladders or stairs, is including a touch indicator at the end. For people hanging on, but focusing their attention on something other than where they place their hand, some cue, such as change in texture or shape, would warn them that they were at the end of the handhold. A knob shape will help prevent the hand slipping from the end of the handhold.

Other Barriers Designs should include barriers where falls might occur. For example, in multistory buildings, people can fall out of windows. Architectural components, like windows and skylights, can be dangerous openings or inadequate barriers. The size of the opening, its placement, and the strength of its frame and infill all determine whether such elements are adequate barriers against falls. Properly placed openings in doors and walls can prevent falls through them. Protect the openings with adequate guard rails, covers or load-bearing screens. A retaining wall that holds back soil in a landscaped setting should be away from walkways and stairs to discourage people from getting near the edge. Railings and shrubs are also effective. Even Moses recognized the need for barriers: "When you build a new house, you shall make a parapet for your roof, that you may not bring the guilt of blood upon your house, if anyone fall from it."[13]

Fall-Limiting Devices If a fall does occur, intercepting it can prevent injuries. There are several kinds of patented fall-limiting devices, some of which attach to fixed ladders or to other climbing and elevated work equipment. A person using a fall-limiting device wears a life belt or harness that attaches to the device with a connection, normally a short, fixed-length rope, called a lanyard. The short length minimizes the fall distance and the deceleration forces that result from stopping the fall. The longer the fall, the greater the chances of injury when the rope becomes fully extended and the body stops. A supporting rope, called a lifeline, must attach with a minimum of slack to an independent support, not to scaffolding or other equipment. Some patented devices are available to connect a lanyard to the lifeline and will control the rate of deceleration in a fall so injury is less likely. A user must position some devices along the lifeline, whereas others move freely, but lock automatically during a fall.

The aim of fall-arresting equipment is to minimize the force imposed on a falling person when reaching the fall limit. OSHA proposed an 1800-lb maximum fall arrest force–the maximum allowed force for someone restrained by fall-arresting equipment–and requires the anchor and lifeline to withstand 5400 lb. ANSI A10.14 limits body belt users to a 10G deceleration force and a full-body harness wearer to 35G. Harnesses are required or highly preferred compared to lifebelts because they distribute the stopping force much better.

An empirical formula for estimating the maximum arrest force[14] (*MAF*) is:

$$MAF = (W + 1.45(kfW)^{1/2})abs/c \qquad (11\text{-}7)$$

where

W = the weight of the falling person
f = a fall factor ($0.1 \le f \le 2.0$) = h/L
h = fall distance in feet permitted by the lanyard
L = total lanyard length in feet
k = rope modulus (pound-force; see Figure 11-3)
a = factor from Table 11-2

b = factor from Table 11-3

s = factor from Table 11-4

c = conversion factor (see Figure 11-4)

The developer of Equation (11-7), which assumes a rigid anchorage point, tested it for accuracy. The calculated results were within ±5% of actual test values. This formula permits one to analyze work situations and evaluate the

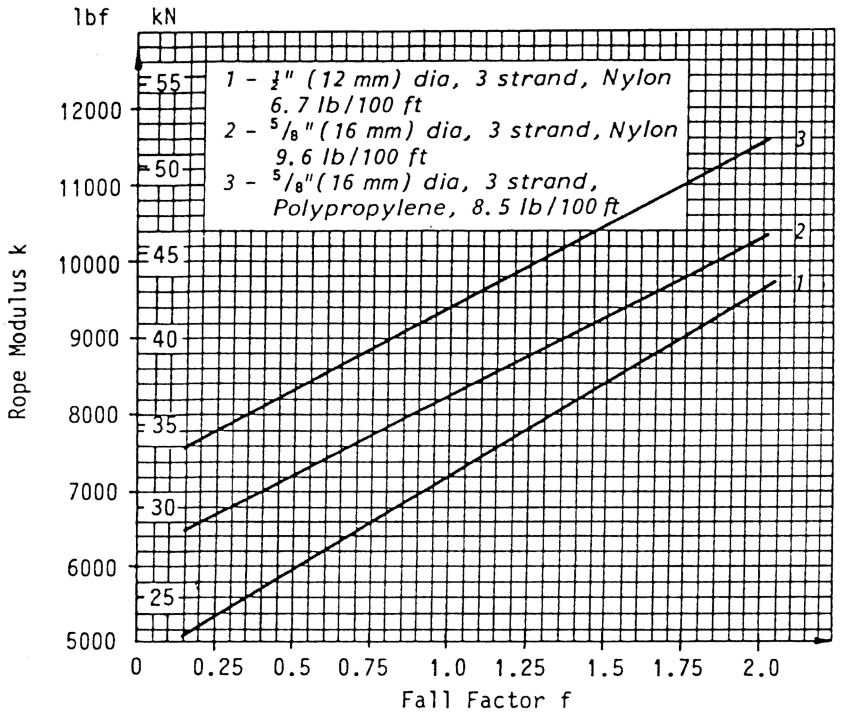


Figure 11-3. Rope modulus (k) versus fall factor (f). (Reprinted with permission from the April 1981 issue of the *National Safety News*, a publication of the National Safety Council. Note: Although the information and recommendations contained in this publication have been compiled from sources believed to be reliable, the National Safety Council makes no guarantee as to and assumes no responsibility for the correctness, sufficiency or completeness of such information or recommendations. Other or additional safety measures may be required under particular circumstances.)

TABLE 11-2 Fall -Arrester Reduction Factor

Type of Fall-Arrester	a Range	a Recommended[a]	Comment
Inertia type, wire rope	0.5–0.7	0.7	for $0 < f < 2$
Inertia type, synthetic	0.75–0.9	0.9	for $0 < f < 2$
Friction type	0.5–0.75	0.7	for $0 < f < 2$
Mechanical lever	0.9–1.0	1.0	for $0 < f < 2$
No FA employed in fall arrest system	N/A	1.0	

Note: [a]Recommended when exact value of fall-arrester reduction factor, a, is not available.

TABLE 11-3 Body Gripping Device Reduction Factor

Belt or Harness	b Range	b Recommended[a]	Comments
Belt (nylon, 2 in. wide)	0.8–0.9	0.9	for $0 < f < 2$
Harness (full body, parachute style)	0.5–0.8	0.8	for $0 < f < 2$
No belt or harness	N/A	1.0	

Note: [a]Recommended when exact value of fall-arrester reduction factor, b, is not available.

TABLE 11-4 Shock Absorber Factor

Type of shock absorber	s Range	s Recommended[a]	Comments
Tear-the-stitches (TS)	0.2–0.6	0.6	for $0.1 < f < 2$
Tear-the-fabric (TF) (synthetic lifeline)	0.3–0.7	0.7	for $0.5 < f < 2$
Tear-the-fabric (TF) (5/16 in. diameter wire rope) No shock absorber used	0.2–0.6	0.6	for $0.2 < f < 2$
	N/A	1.0	

Note: [a]Recommended when exact value of fall-arrester reduction factor, s, is not available.

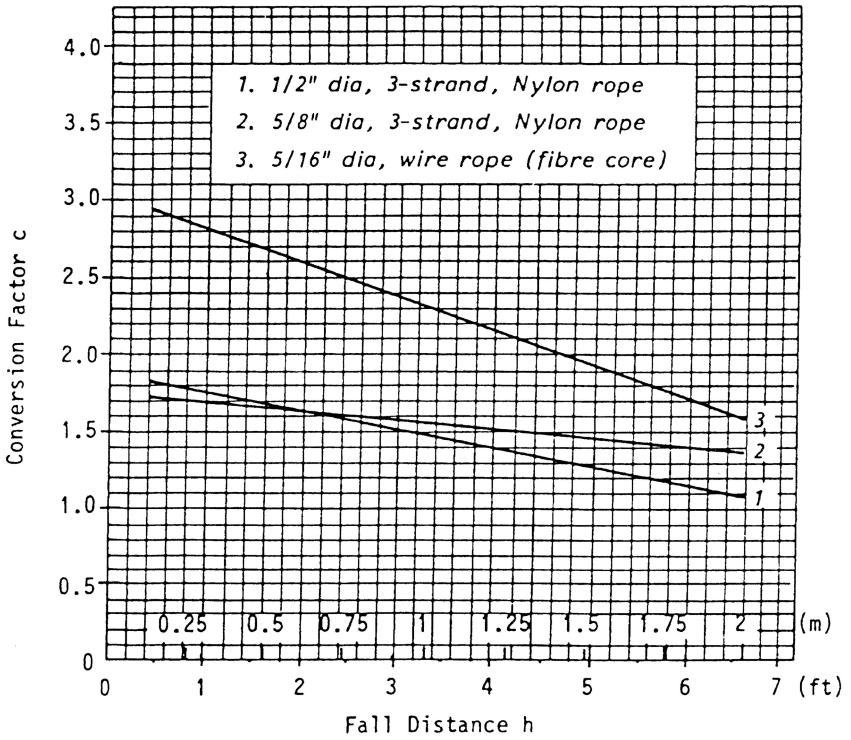


Figure 11-4. Conversion factor (c) versus fall distance (h). (Reprinted with permission from the April 1981 issue of the *National Safety News*, a publication of the National Safety Council. Note: Although the information and recommendations contained in this publication have been compiled from sources believed to be reliable, the National Safety Council makes no guarantee as to and assumes no responsibility for the correctness, sufficiency or completeness of such information or recommendations. Other or additional safety measures may be required under particular circumstances.)

arresting forces of shock-absorbing mechanisms. In actuality, however, reduction varies with the kind of shock-absorbing device used. The arresting force is lower than that calculated when the anchor point is not rigid, but has some deflection. Also, the fall distance does not include any clearance required for elongation of the fall-arrest system (see Table 11-5) or the extension of the arms or legs of a supported person.

Safety Nets Some fall protection is impractical during construction of bridges, towers, and other structures. An alternate fall protection is safety nets that stop a worker's fall. The nets and anchorages must meet standards and pass tests. Properly placed nets minimize the fall distance. Again, the longer the fall, the greater the likelihood of injury. A net intended for stopping a falling person is a personnel net and one intended for stopping falling materials is a debris net. Debris nets must be strong enough to stop the size and weight of objects that could fall. Their mesh may be as small as ¼ in.

TABLE 11-5 Approximate Additional Elongation of Fall-Arrest System Due to Shock Absorber (ft)

Type of shock absorber	Starting force (lb)	Additional elongation (ft)
Tear-the-stitches	550	3.6
Tear-the-fabric	1000	2.9

whereas the maximum mesh for a personnel net is 6 in. A safety net may serve both purposes. Clearing debris regularly from the net will prevent it from injuring a falling worker.

Catch Platforms Catch platforms are flat surfaces placed at the edges of sloped roofs. They are normally 2 ft wide. They prevent someone who slides down the roof from falling to the ground. They may not be necessary if workers use lifelines.

Preventing Objects from Falling

Housekeeping If people leave objects such as tools, waste, work materials, and other items lying around on an elevated surface, there is a chance that they will fall onto the surface below or strike someone. Overflowing trash containers create the same hazard.

Standard Guardrail As explained earlier, the standard guardrail has a toe board and sometimes infill to prevent objects from falling to lower levels.

Fall Zone A fall zone is a fenced or guarded area where people at lower levels cannot enter so that falling debris will not strike them. The guarding consists of overhead and side protection of the occupied area. The protecting material must have enough strength to provide protection for the size and weight of objects that could potentially fall. Side protection protects occupants from splattering or scattering material.

Overhead Protection In some operations, materials travel above areas where there are people. Elevated conveyors and parts lines in assembly operations are common examples. Overhead protection can prevent materials from falling on those below. From time to time, someone must remove fallen materials from the overhead screen or barrier. The barrier must be strong enough to support workers during the removal activities.

Covers Pipes, ducts, conveyors, and other equipment pass through holes in floors and walls. The holes may be oversized for installation and maintenance activities. Cover openings to prevent someone from falling through them or items from falling on anyone below. When covers are not in place, there is a need for other forms of protection, such as barriers.

Stacking and Storage Proper stacking and storage of materials can prevent objects from falling. Keeping stored items away from openings and not stacking them above barriers will help. Adequate work space and traffic aisles minimize the danger of running into stacked items. Items on storage racks can fall on those below. Impact barriers for material handling equipment can reduce the danger of knocking stacked materials over and damaging storage racks. For many kinds of stacked materials, stepping them back with each tier increases stability of the stacked materials. Crossties may also be necessary. Chapter 16 discusses other storage requirements for fire protection.

Reducing Energy Levels

In some cases one can control energy in a falling body or for a body that could fall. One method is minimizing the vertical travel distance. Another is minimizing the weight of elevated objects.

Reducing Injuries

Cushion the Impact Preventing falls is always the primary goal. However, a variety of actions can prevent injury to people who do fall. One is increasing the stopping distance. Padding can help. Some sports facilities have pads on walls, poles, and other vertical surfaces. Even some auto race tracks now have padded walls at the track to protect drivers hitting the walls. In some sports, like gymnastics, floors surfaces have thick pads. In motor vehicles, the dash, visors, and other interior surfaces have padding that absorbs energy. For some fires in buildings one type of rescue device is a large inflated cube that people can jump on when leaping to safety.

Fall-arresting devices cushion the impact and extend the distance over which deceleration occurs. That reduces the rate of deceleration.

Distribute the Forces By distributing forces at impact over a large area, there is a reduction in the likelihood of injury. Pads and cushions not only extend the stopping distance, but distribute the forces over a larger area. The function of a suspension system inside a hard hat or helmet is to distribute the impact force over a large area. Knee pads for flooring installers serve this same function. Knobs and controls that one can strike can be flat or recessed to enlarge the impact area. Protruding elements on toys made from deformable materials help distribute loads if a child falls on them. A safety harness will usually distribute the force of a fall over a larger area than a lifebelt.

11-5 APPLICATIONS

There are many kinds of walking and working surfaces and equipment involved with them. The principles discussed in the preceding text apply to them. This section will look at several applications in more detail.

Stairs

Stairs are the most common device for helping people move from one elevation to another. Normally built on structural

supports called stringers, the main parts of stairs are the treads (the surfaces stepped on) and the risers (the vertical faces between the treads). Most treads extend beyond the face of the risers. This leading edge is the nosing.

As long ago as the ancient Egyptians,[15] some stairs standards existed. Now there are several standards for stairs design. They are in OSHA regulations, building codes, life safety codes, books on carpentry, and other sources.

There are several factors that affect stairs safety. They include uniformity of dimensions, resistance, slope, visibility, structural strength, width, tread depth, placement, and other features.

Uniformity Stairs should have uniform dimensions for all steps in a flight. People walking up or down stairs intuitively establish measures of what stair dimensions are and expect the dimensions found in the first step to occur for the others. A sudden change in dimensions can cause stumbling similar to when a person misjudges the number of steps.

Slip Resistance Stair treads must have the same slip-resistance characteristics that floors do. When people walk on stairs, they expect the resistance to be the same or very similar to adjacent surfaces. Sudden changes may cause slipping or stumbling.

Slope The slope of a stairway is the ratio of riser height to tread depth. The preferred slope for stairs is about 30–35 degrees from horizontal. Standards differ on actual values and slopes may fall between 20 and 50 degrees. Tread and riser dimensions should have dimensions that are easy to create using a tape or rule. Otherwise, it is difficult to lay them out or to buy them. Table 11-6 lists some combinations of tread and riser dimensions that result in slopes between 30 and 40 degrees.

TABLE 11-6 Some Acceptable Combinations of Stair Riser and Tread Dimensions

Angle to Horizontal	Riser (in.)	Tread Depth (in.)
30°35’	6 ½	11
32°08’	6 ¾	10 ¾
33°41’	7	10 ½
35°16’	7 ¼	10 ¼
36°52’	7 ½	10
38°29’	7 ¾	9 ¾
40°08’	8	9 ½
41°44’	8 ¼	9 ¼
43°22’	8 ½	9
45°00’	8 ¾	8 ¾
46°38’	9	8 ½
48°16’	9 ¼	8 ¼
49°54’	9 ½	8

Source: 29 CFR 1910.24 (e).

Visibility Visibility on stairs is very important. It includes having enough light to see steps easily and avoiding glare that obscures the ability to see steps. For example, a window or door located at the base of a stairway can create glare that makes it difficult to see steps.

Minimum lighting levels in some standards require 1–5 footcandles of light. However, when one enters a building from bright, sunny outdoor conditions, minimum lighting levels for stairs are inadequate. Someone’s eyes do not have time to adjust quickly to the lower light levels. Reduced visibility may lead to a fall.

Visibility also includes clear definition of tread nosing and avoidance of surface finishes and textures that make one step blend in with another.

Structure Stairs must carry an expected load. Standards for stairs include minimum load capacity. OSHA requires stairs to carry five times the normal live load and not less than a moving concentrated load of 1000 lb. In fire exiting, one often plans exit stairs to carry the maximum concentration of people for which there is space.

Width Life safety codes define stair widths for exiting during fires. The standard exit unit, the width needed by one person, is 22 in. Most stair standards require more width than one exit unit. Chapter 16 gives more information on life safety.

Distractions One study[16] filmed people walking down stairs. The study found that the people who stumbled or fell usually did so at the same location on the stairs. There were no changes in the physical characteristics of the stairs that might cause the falls. Researchers concluded that as people’s heads moved below the floor opening they became distracted by the sudden view of the large room. Many retailers have experienced similar effects when placing displays or pictures on landings or in view of people using stairs. Enclosing stairs or otherwise preventing such a visual distraction can help solve this problem.

Other Features The number of steps included in a staircase can create hazards. Users do not always see a one- or two-step change. They trip over the one- or two-step change and fall. Consequently, for small changes in elevation, ramps are better than steps.

Because climbing stairs is hard work and too many steps can be tiring, multi-storied buildings and long flights of stairs should have landings to give people a chance to recover.

The base of a stairway should be free of hazards. For example, falling down a stairs into a glass wall or door can cause severe injury. The base of a stairway should also be free of objects that could cause injury. Many people use stairs for storage because they do not want to carry items all the

way up or down. The stored items can cause tripping or slipping. Stairs should be free of waste, like paper or other objects, that can create tripping or slipping hazards.

Stairs must have handrails that will support a person's weight. Handrails provide at least two-point support (one foot and one hand) during ascending or descending activities. Handrail cross-sections should be easy to grasp. Place handrails according to life safety codes and other standard specifications. In addition to handrails along the sides of stairs, wide stairs should have one or more handrails located at intermediate locations across the width of the stairs.

Ramps

Ramps have a hazard related to their slope because a force component runs parallel to their surfaces and could contribute to slipping. To reduce slipping chances, ramps must have a limited slope and a slip-resistant finish. The preferred angle for a ramp is less than 15 degrees; the maximum for access by the handicapped is usually 5 degrees or less.[17] For slopes greater than 15 degrees, traction is very poor without cleats. Ramps may have one or both sides open to the lower level. Unless protected by guardrails, someone could fall from such ramps. Ramps need handrails to assist those negotiating them. Long ramps need landings similar to long stair runs.

Dock Plates and Gangplanks

Dock plates and gangplanks bridge gaps between a platform or surface and a vehicle or ship. They often serve both pedestrian traffic and material handling vehicles. Major hazards for dock plates and gangplanks are structural failure, sliding out of position, falling off supporting edges and difficulty in placing them into position. Slipping and tripping hazards and controls for them also apply to dock plates and gangplanks.

To reduce the possibility of structural failure, dock plates and gangplanks must carry anticipated loads. They should have labels to show load capacity. There should be regularly scheduled inspections to find defects or failures. Repair defects or damage or replace the dock plate or gangplank.

To help prevent vehicles from running off their edge, dock plates should have a curb or lip along their sides. Most dock plates use lightweight materials, like aluminum or magnesium, to make them easier to handle. Some even have handholds. Some have features that facilitate materials handling equipment or forklift trucks. Some dock plates are integral parts of loading platforms and have powered devices to adjust them to different positions without manual lifting.

Dock plates will slide if they are not locked into position. Some of the devices for locking them into position include stop pins, cleats or built-in flanges and blocks. Anchoring methods should not create tripping hazards.

Ladders

Types There are many types of ladders. They are classified by material of construction (wood, metal), load capacity, function and design. Some ladders are classified as type I, II, or III, depending on the standard loads (200, 225, and 250 lb) used for certain tests. Most ladders are manufactured and sold for use. However, some ladders are job-made ladders, assembled at job sites. Ladders can be portable or fixed in place. Common types of portable ladders are step, platform, straight and extension ladders. Multipurpose ladders adjust to serve as several single-purpose ladders. Some ladders, such as those on truck trailers, have custom designs to fit around other design elements. There are many standards for ladder construction.

Hazards and Controls Ladder rungs or steps must have slip resistance to prevent slips and falls. Especially for ladders used around wet, oily, and muddy conditions, rungs or steps must have side protection, so a foot cannot slip sideways and off them. There must be enough space between a rung and a wall behind it so the arch of the foot, not just the toes, can fit on the rung. Flat rungs or steps should be very near horizontal when the ladder is in position for use. If not, they create sliding forces parallel to rung surfaces.

Ladders must withstand reasonable forces applied to them without collapsing or having other structural failures. Inspections will help locate defects and assure integrity. Repair or throw away defective ladders. Misuse and improper use can create structural failure. For example, an extension ladder must have a minimum amount of overlap between sections. If not, the bending load at the connection will cause failure. The exact amount depends on the ladder length.

Ladders can tip over sideways, tip over backwards or slip out at the bottom, depending on ladder type. If the user of a straight or extension ladder leans to one side to reach something and the resultant force for the ladder and occupant falls outside the support area, the ladder will tip over. An outrigger attachment at the top will reduce this hazard. Anchoring or tying a ladder to a support structure will also prevent sliding. All ladders should rest on a solid base because on soft soil the feet may sink in, causing tipping. Some ladders have adjustable length feet to keep a ladder plumb on uneven surfaces.

Spreaders on step or platform ladders must be fully opened and locked to prevent the ladders from collapsing or tipping. Fully opened and locked spreaders can prevent them from "walking," twisting and closing.

As one climbs a ladder, the center of mass formed by the occupant and ladder goes higher. The higher the center of mass, the easier it is to tip a ladder over. Users should never stand on upper rungs or steps. The type and length of ladder determine which rungs one should not use.

Proper positioning will prevent straight or extension ladders from tipping over backward. The preferred angle is 75 degrees from horizontal. A rule of thumb is to place the feet of these ladders so the horizontal distance from the support point at the top to the ladder feet is ¼ the working length of the ladder. If the angle formed by the base with the vertical is too large, these ladders will slide out at the bottom. To prevent sliding, tie off the top and restrain the bottom. Special feet are available on some ladders to reduce the chances of sliding.

When a straight or extension ladder provides a route to a higher work surface, the top of the ladder should extend 3 ft or more above the upper surface. This provides a handhold when getting on or off the ladder and allows a user to step from the ladder to the upper surface.

Metal ladders can conduct electricity. Therefore, do not use them around electrical conductors or equipment.

Inspect ladders regularly and before use for cracks, wear, sway, breaks, bends, and other kinds of damage. Examine extension locks, bolts, fasteners, and feet for defects or looseness. Remove defective ladders from service until properly repaired. Destroy and replace unrepairable ladders.

People must learn how to use ladders correctly. They need to know how to select them for the job, and how to place, use, carry and store them. Ladders are not intended for transporting materials. Carrying an object while climbing a ladder violates the three-point support principle because one cannot grasp the ladder at all times. A slip is very likely to lead to a fall. Hoist materials and tools to the upper work level. Users should clean their shoes and ladder steps or rungs to reduce the chances of slipping.

Scaffolds

Types There are many kinds of scaffolds: wood, metal, fixed, moveable. Many scaffolds have patented designs and features. There are tubular, suspended, and special classes of scaffolds. There are standards for most of these. Large scaffold systems require structural design and analysis.

Tubular Scaffolds There are two main types of tubular scaffolds: frame types and tube types. Both are modular and erected from parts designed to fit particular job requirements. Frame types have fewer individual parts and connections and use standard frame components to assemble and lock parts together.

Suspended Scaffolds Hanging scaffolds are classified by the number of suspension points. The type of anchoring and suspension system helps classify hanging scaffolds. Single point suspension scaffolds include a boatswain's chair and a single person work cage. Suspended scaffolds usually hang by ropes from cornice hooks, outrigger beams or other anchors. Work platforms assembled at a job site include the platform, guardrails and suspension. Manufactured stages have preassembled parts. Powered or manually operated pulleys, winches or other devices move platforms up and down. Proper rigging is very important.

Special Scaffolds There are many kinds of specialty scaffolds. Ladder jacks attach to straight or extension ladders. Two ladders with ladder jacks will support planks between them. Users nail roofing brackets to roofs with steep slopes or suspend them with ropes and proper anchors. The brackets support planks between them that workers stand on. After roofing is complete, users remove the planks and brackets.

Another special type of scaffolding, called slip form scaffolding, combines concrete forms with scaffolding. Users raise the scaffolding and forms as previously poured concrete cures. In some cases, these systems allow for continuous pouring of concrete. However, concrete must cure sufficiently after pouring before anchoring slip form scaffolds at a new level.

Planking Planking for scaffold work surfaces may be wood or metal. Wood planking is a special grade of lumber free of knots and other defects that would reduce load capacity. Regular grades of lumber are not suitable for planking. Cleats may lock planks in place. Many scaffolding accidents are the result of unsecured and loose planks.

Loads A major hazard for scaffolding is overloading and structural failure. Often scaffolding is load tested before use. Standards for scaffolding rate them for light, medium, and

CASE 11-4

April 27, 1978. Willow Island, West Virginia. Construction of a concrete cooling tower for a power station had reached 166 feet. Concrete from the previous day's pour started to collapse and took wooden forms and metal scaffolding with it. Fifty one construction workers on the scaffold fell to their death.

An investigation identified the probable cause as the imposition of construction loads on the shell before the concrete poured the previous day had gained enough strength to support the loads.[a]

[a]www.nist.gov/manuscript-publication-search.cfm?pub_id=908824; *Investigation of Construction Failure of Reinforced Concrete Cooling Tower at Willow Island, West Virginia (NBS IR 78–1578).*

CASE 11-5

11-5a

August 19, 2011, Hasselt, Belgium. About 60,000 people attended an open-air festival. A thunderstorm with violent winds came on quickly. It destroyed the canvas concert tent and knocked down scaffolds supporting the concert lighting. The incident killed 5 people and injured about 140. Officials ended the festival and dispersed attendees with specially scheduled buses and trains.

11-5b

One week earlier, August 13, 2011, Indianapolis, Indiana. An evening, outdoor concert was getting underway at the Indiana State Fair. About 12,000 people attended. A thunderstorm with strong winds arrived. The temporary structure supporting spotlights and other equipment on top of the stage collapsed. Seven people died and more than 40 needed medical treatment.

There were several investigations of the incident. The complexities of the case created a string of liability claims, litigation filings and insurance and other monetary settlements.

A report of an investigation authorized by the State of Indiana and conducted by Witt Associates identified planning for emergency situations as inadequate and made several recommendations to prevent similar cases in the future.[a]

The State Fair organization authorized a forensic investigation that included analysis of the structural failure.[b] The State of Indiana published documents and reports related to the case.[c,d,e]

[a] www.in.gov/sfc/files/041212_WA_Final_ISFC_Report.pdf
[b] www.thorntontomasetti.com/news/spotlight/199-indiana_state_fair_commission_investigation_report
[c] www.in.gov/sfc/
[d] www.in.gov/sfc/2340.htm (Documents)
[e] www.in.gov/sfc/2343.htm (Investigative Reports)

heavy duty, depending on designed working loads of 25, 50 and 75 lb/ft^2, respectively. All load-carrying components must meet design standards. Inspect scaffolds before use. Complete assembly of all fastening bolts, connectors, and bracing is important. Check ropes, suspension fittings, wear on ropes, counterweight adequacy, outrigger beams, and clamp tightness.

Tipping For ground-supported scaffolds, a hazard is tipping over. Placing each leg on a solid base will prevent tipping. Tying a scaffold to an adjacent building or structure may prevent tipping. In some situations, scaffolds need rope anchoring to prevent tipping over.

Falls Falls of people and objects from scaffolds are another hazard. Controls discussed earlier apply.

Use Users of scaffolds must learn proper assembly, testing, inspection and use. A qualified scaffold designer should oversee many scaffold applications, particularly large and complex scaffolding systems.

Elevated Work Platforms

Some work sites where assembly of scaffolding would be expensive require a temporary work platform at some height. Some mobile devices provide vertically adjustable work platforms and some are self-propelled. One type of mobile device is an aerial basket or "cherry picker," which can move vertically and horizontally. Other types may only telescope vertically. Platforms used around electrical equipment must be insulated from electrical hazards. Properly positioned outriggers on some work platform devices provide stability and help ensure that the telescoping section is plumb. The use site may need preparation to be sure that it is level. The surface should also be solid to prevent sinking of supports and tipping of equipment.

Some powered platforms have controls at the platform or basket. Usually there is a second set of operator controls at ground level for general and emergency use. The platform should lock at the level desired and not be subject to free fall if there is a power failure. Users must learn how to set up and operate elevated work platforms. Lifelines connect fall protection harnesses or safety belts to the platform to prevent workers from falling. Controls should be fail-safe and have features to prevent inadvertent actuation. Some controls interlock to level indicator switches to prevent tipping the equipment over.

Skylights

Skylights are transparent structures placed over roof openings to provide natural lighting to interior spaces. Skylight units can be round or rectangular. Architectural standards for

CASE 11-6

October 27, 2010, South Bend, Indiana. Declan Sullivan, a student excited to have the opportunity, was video taping practice for the University of Notre Dame football team that day from atop an elevated scissors platform. He worried about the wind that afternoon. Records show the wind had been around 30 mph with gusts to about 40 mph or higher. A day earlier the team had practiced indoors because of tornado warnings.

As is common for many schools and football teams, coaches capture player practice drill performance with elevated video cameras. A camera operator often stands on an elevated surface. Frequently, hydraulic scissor lifts provide the surface for video cameramen.

Apparently, a wind gust swept through the practice field and toppled the tower. Mr. Sullivan died from the fall.

The event spurred several investigations and discussion about football practice-related decision-making and who has responsibility for all personnel involved in a practice session. Some schools created or changed polices and procedures related to use of scaffolds and portable towers for video taping athletic practices. Many of the procedures covered anchoring of elevated work platforms, decisions for use in windy or adverse conditions, and safety procedures for their use.

CASE 11-7

Champaign, IL. An electrician was about to repair a large, roof-mounted HVAC unit on a flat roof section of a production plant. The worker used a skylight located alongside the platform as a convenient step to the platform. The skylight was located about 20 feet above the concrete floor of the plant. Other than the skylight dome, the opening had no guarding around the dome or fall-preventing barrier below the dome.

When the worker used the skylight as a step, the skylight dome fractured. He fell to the plant floor below. He suffered severe injuries including spinal injuries at the neck. He did not recover and became a quadriplegic, needing constant care.

The skylight had been in place for several years and the sunlight had caused the plastic dome to deteriorate, becoming brittle and developing cracks.

most skylights address weather resistance to prevent leaks from rain and snow but do not address strength sufficient for someone to stand on them. Especially when located on roofs that can also become work surfaces, skylights need surrounding barriers to keep workers from stepping on them or fall protection structures in the openings the skylights fill.

ADA Considerations

In the United States and other countries, standards for walking and working surfaces must account for people with disabilities. The standards have specifications for people in wheelchairs and those with disabilities not involving use of wheelchairs. The standards cover a wide range of facility types, from residences, to medical, and many other kinds of public facilities. The standards address much more than walking and working surfaces. The U.S. Department of Justice has responsibility for US standards falling under the Americans with Disabilities Act (ADA).[18]

EXERCISES

1. A fixed staircase is to be constructed between two floors of a building. The distance between floors (surface to surface), is 140 in. Using OSHA stairs criteria, determine:
   (a) how many steps are needed
   (b) the depth of each tread and the height of each riser
   (c) the stairs slope for your solution
2. A straight ladder that has a length L of 35 ft is placed against a building that is 50 ft tall. The ladder forms the desired angle with the wall, the base being L/4 ft from the wall. Assume the ladder weighs 90 lb and the person climbing on it weighs 200 lb. Assume that the person's center of gravity acts 3 ft vertically from the point of contact on the ladder rungs. The coefficient of friction between the ladder feet and the surface they rest on is 0.5.

(a) How far up the ladder can the worker go before it slides out at the bottom?

(b) If the worker stands 3 ft from the top of the ladder, how much force is required to tip the ladder away from the wall, assuming the force is acting horizontally against the top of the ladder? Ignore vertical forces at the wall.

3. A worker is struck by a 30 in. long piece of pipe weighing 1.92 lb/ft. The pipe fell out of an overflowing trash can from a platform at a level 70 ft above the worker's head.

(a) What was the velocity of the pipe when it struck the worker?

(b) What is the kinetic energy of the pipe at the point of impact?

4. While walking on a level surface, a person exerts a force F of 100 lb from the hip joint to the shoe of the forward foot just at the time the forward foot is planted fully. Assume the leg forms an angle of 15 degrees with the vertical. What coefficient of friction is required to prevent the shoe from slipping on the floor?

5. A hemispherical plastic skylight is located on a roof directly adjacent to a work surface for air conditioning equipment. The skylight design will not carry the weight of a person. The work surface is about 44 in. above the skylight and there are no access steps to it. Which standards should one apply to this situation? What forms of protection would protect a worker who might do the following?

(a) fall from the platform onto the skylight

(b) step on the skylight as a way to get onto the platform?

6. A guard rail at the front row of the second deck of a sports stadium is 33 in. high. When someone sits back normally in a seat with a seat back in that section, the angle between the eye and the near edge of the playing field is 35 degrees below horizontal.

(a) Can an average person see over the rail? (Use anthropometric data to make an estimate.)

(b) Suggest how you would design the railing to prevent a front row fan from falling over the edge.

7. Some public events trigger a sequence of lawsuits and insurance claims to gain compensation for injuries and deaths. Research the lawsuits and insurance claims that resulted from the failure of the structure covering the stage at the Indiana State Fair covered in Case 11-5b. Compile a list of claims identified.

REVIEW QUESTIONS

1. Define tripping.

2. Identify at least three tripping hazards.

3. What factors contribute to lack of visibility of tripping hazards?

4. What controls will help remove tripping hazards?

5. Define slipping.

6. Identify at least three hazards that may cause slipping.

7. Which activities and environmental conditions contribute to slipping?

8. Name three types of instruments for measuring slipperiness.

9. Name five controls to prevent slipping.

10. Which factors contribute to injury from falls?

11. What are four objectives of fall protection?

12. What kind of controls prevent people from falling?

13. Identify the elements of the standard guardrail and the function of each.

14. Explain why guardrails should be at least 42 in. high.

15. Explain the components of fall-limiting devices and the function of each.

16. Name seven controls for preventing objects from falling.

17. What are two ways to reduce injuries from falls?

18. Identify hazards and hazard controls for each of the following:

(a) stairs

(b) ramps

(c) gangplanks

(d) dock plates

(e) ladders

(f) scaffolds

(g) elevated work platforms

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CHAPTER 12

ELECTRICAL SAFETY

The use of electricity as a source of power has become extremely commonplace. There are very few homes in the United States and other developed countries that do not have electrical service. We are in the electronic and information age, in which electrical and electronic equipment adds convenience and provides new communication and information capabilities.

As with all forms of energy, electricity has certain hazards associated with it. The goal is to eliminate or control these hazards.

This chapter does not cover advanced electrical systems involving three-phase conductor systems, typical with 220 and higher volts. While safety fundamentals apply, readers interested in such complex systems need advanced knowledge to understand their unique hazards and specialized controls.

12-1 FUNDAMENTALS OF ELECTRICITY

An understanding of the hazards and safeguards for electricity begins with an understanding of basic electrical phenomena.

Ohm's Law

The most important principle of electricity is Ohm's law, which defines the flow of electrical energy. It states that electron flow called current I is a function of electrical potential V between two points and the resistance R between them. Ohm's law is stated as:

$$I = V/R \tag{12-1}$$

where

I is in amperes

V is in volts

R is in ohms

Resistance is a function of the material over which electrons move. If electrical energy or charge is to move from one point to another, there must be a difference in energy level between the two points. There must also be some conductive material that connects the two points.

Electrons will flow primarily through the path of least resistance, if there is more than one path between two points that differ in electrical energy level.

Current Density

Current density is the amount of current flowing through a conductor per unit of cross-sectional area. If the area is large, the current density is low. Current and current density are important for safety.

Resistance

All materials exhibit some resistance to the flow of electricity. Materials that allow electrons to flow easily are conductors. Some good conductors are copper, other metals, water, and electrolytic fluids. Insulators are materials that do not allow electrons to flow easily. Examples of insulators are rubber, glass, wood, air and other gases, and most plastics.

The total resistance to the flow of electrons is the sum of all resistances presented by the flow path. One or more materials can create the flow path. For a single material of length l and a given cross-sectional area, the resistance R is given by

$$R = \rho l = l/\sigma \tag{12-2}$$

where

ρ is resistivity in ohms per unit length

σ is conductivity in unit length per ohm

Reference tables list resistivity and conductivity of various materials. Equation (12-2) shows that resistivity and conductivity are reciprocals, with conductivity the more commonly used property. Table 12-1 gives resistivity for selected American wire gauge copper wire sizes.

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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TABLE 12-1 Electrical Resistivity of Selected Copper Wire

Gauge	Resistivity ρ (ohms per 1000 ft at 20 °C)	Cross-Section (in.^{2})
0 Gauge	0.09827	0.08289
4 Gauge	0.2485	0.03278
10 Gauge	0.9989	0.008155
12 Gauge	1.588	0.005129
14 Gauge	2.525	0.003225
18 Gauge	6.385	0.001276

Heating

A material creating a resistance to electron flow introduces heating, another important phenomenon for safety engineering. The temperature of a conductor will rise as the current flow increases. The energy lost to resistance changes to heat energy, a process called Joule heating. The amount of heat produced can be determined from Joules law,

$$P = I^2R \tag{12-3}$$

where P is power in watts.

The increase in temperature depends on the amount of heat produced during Joule heating. Temperature rise also depends on how well heat transfers to the surrounding environment through convection, conduction, and radiation.

Another class of electrical heating is inductive heating, which occurs when metal is inside a magnetic field. Inductive heating is highest inside an inductive coil. When high levels of alternating current pass through the coil, the magnetic reluctance of the metal causes it to heat. Any metal in the magnetic field, including jewelry worn by someone, will heat.

Arcing

Arcing occurs when current flows through air between two conductors that are not in direct contact. Arcing produces light as electrons move across the gap between the conductors. Because dry air is a poor conductor, the distance over which an arc will travel between conductors is small. The distance over which arcing will travel in dry air increases with an increase in voltage between the conductors. We see arcing in the form of lightning. We see it when someone opens or closes a switch or other electrical contact. We see it in the contact between brushes and commutator in many electric motors. Arcing is a function of the voltage between conductors, the conductivity of the medium between them and the distance between conductors.

Classification

There are classifications for electrical systems based on voltage, current type (alternating or direct current), and hazard potential. The classifications differ by country and standards organization. Some standards organize electrical systems functionally as well.

Some frequently cited electrical standard setting organizations include:

- National Fire Protection Association (NFPA) (National Electric Code, NEC)
- Institute of Electrical and Electronics Engineers (IEEE) (National Electrical Safety Code, NESC)
- National Electrical Contractors Association (NECA) (National Electrical Installation Standards, NEIS)
- National Electrical Manufacturers Association (NEMA) (Electrical Standards and Product Guide, ESPG)
- Occupational Safety and Health Administration (OSHA)
- American National Standards Institute (ANSI)
- International Electrotechnical Commission (IEC)
- CSA Group (Canada)
- American Association of Medical Instrumentation (AAMI)

There are many other standards organizations around the world that publish standards for electrical and electronic systems.

12-2 ELECTRICAL HAZARDS

Electricity and electrical equipment create or contribute to several hazards. The most common ones are electric shock, heat, fire, and explosion. Electricity may produce other hazards indirectly. For example, when electricity energizes equipment, mechanical hazards may result. Some electrically powered devices produce harmful levels of X rays, microwaves, or laser light. Certain equipment may create dangers from magnetic fields. Haddon's energy theory (see Chapter 9) helps people analyze electrical hazards and identify controls.

Standards organize electrical hazards by location and conditions into classes, divisions, groups, and temperature code. Table 12-2 provides definitions for major classes based on the hazardous material in a location's surrounding atmosphere.

There are many indirect hazards that electrical and electronic equipment create or to which they contribute. For example, failure of electrical power can make building interiors dark and exiting dangerous or impossible. Failures of computer equipment or electronic sensors can add to hazards in processes or control systems in aircraft, industrial plants, or other places. Radio frequencies, field-induced currents or static buildup can interfere with critical

TABLE 12-2 Major Hazardous Location Classifications[a]

Class	Description
I	Locations where flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures
II	Locations that are hazardous due to the presence of combustible or conductive dusts
III	Locations that are hazardous due to the presence of ignitable fibers or flyings not likely to be in suspension in air in quantities sufficient to produce ignitable mixtures. Examples: wood chips, cotton, flax and nylon

Note: [a]See NFPA 70 and NFPA 499.

electronic equipment and can cause failures unless adequately shielded or insulated. This book does not detail these kinds of electrical and electronic hazards and controls for them.

Electric Shock

Electric shock refers to current passing over or through a human body or its members and to the injuries that result. For electric shock to occur, a person must become part of an electric circuit. A person must become a conductor between two points that differ in electrical potential.

Electric shock effects are mainly a function of the amount of current that flows through the body. Besides current, other properties of electricity that affect the severity of shock include voltage, type of current [direct current (DC) or alternating current (AC)] and frequency of alternating current. Length of exposure and the part of the body through which the current passes are also important determiners of the probability and severity of injury. Table 12-3 summarizes the effects. Figure 12-1 presents shock effects for electricity of various forms. In general, alternating current is more dangerous than direct current and 60 Hz is more dangerous than high frequency current.

As little as 35 mA of current has produced heart fibrillation when applied directly to heart tissue. Currents as low as 50 mA at 120 V and 60 Hz have caused death. There is a threshold current at which a tingling feeling occurs. At higher current levels, there is pain. At even higher currents, muscles contract involuntarily. Normally, the brain sends electrical impulses to muscles causing them to contract. An externally applied current can produce the same result and at some level, the external current dominates brain impulses. People who have experienced involuntary contraction say they "can't let go." The effect may vary, depending on the muscles affected by the current. If chest muscles contract from an external current, the normal contraction-relaxation cycle for breathing cannot occur. This can produce asphyxiation. A shock that produces muscle contractions will often cause sudden contractions at many locations in the body. People who "jump" from a ladder when shocked or "jump" away from a source of shock are often experiencing rapid involuntary muscle contraction.

Certain currents cause fibrillation, a disruption of the normal, cyclical contraction of heart muscle. Compared to other muscle tissue, heart muscle tissue has the unique ability to generate an electrical pulse. One location in the heart muscle dominates and starts the synchronous contraction process of heart muscle. An externally applied current can disrupt the synchronous pulse and cause fibrillation. Fibrillation is the random current of the heart muscle. Each local element of heart tissue generates its own current, which causes local contraction. During this random contraction of local tissue, the heart loses coordinated pumping action.

TABLE 12-3 Effects of Electricity on the Human Body

	Current (mA)					
	Direct		60 Hz		10,000 Hz	
Effect	Men	Women	Men	Women	Men	Women
Slight sensation on hand	1	0.6	0.4	0.3	7	5
Perception threshold	5.2	3.5	1.1	0.7	12	8
Shock, not painful, muscle control not lost	9	6	1.8	1.2	17	11
Shock, painful, muscle control not lost	62	41	9	6	55	37
Shock, painful, let-go threshold	76	51	16	10.5	75	50
Shock, painful and severe, muscle contractions, breathing difficult	90	60	23	15	95	63
Shock-possible ventricular fibrillation from 3 s duration	500	500	100	100	–	–
Short shocks lasting t seconds	–	–	$165(t)^{1/2}$	$165(t)^{1/2}$	–	–
High voltage surge	50[a]	50[a]	13.6[a]	13.6[a]	–	–

Note: [a]Watt-seconds or joules.

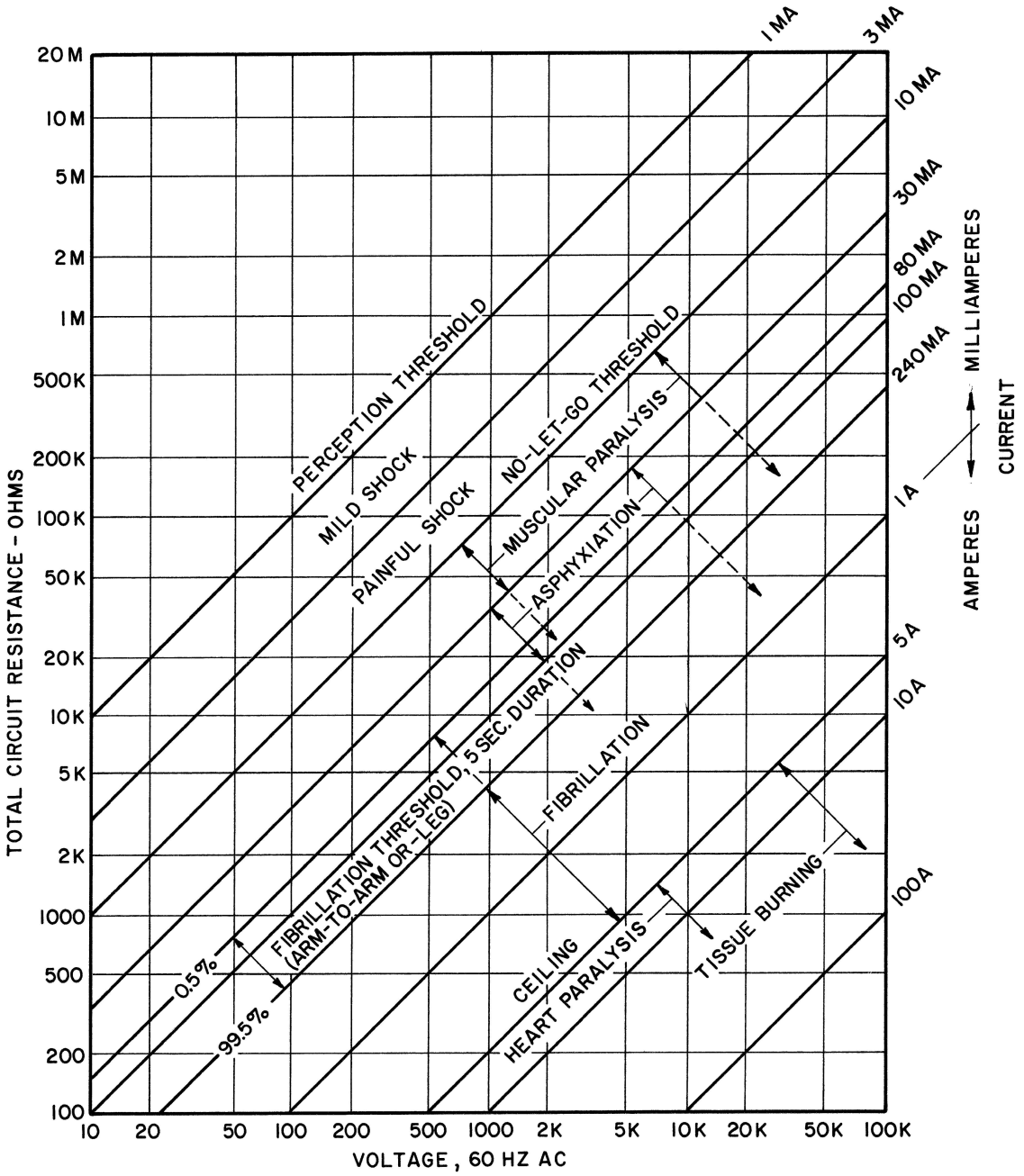


Figure 12-1. Effects of 60 Hz AC electric current on a 150 lb man. (Reprinted by permission. Copyright © by The Instrumentation, Systems and Automation Society, 1965. From *Electrical Safety Practices*.)

Probability current is the current that is likely to cause fibrillation. For 60 Hz current, the fibrillation threshold probability current I, for an arm-to-arm or arm-to-leg connection is given by Lee[1] as

$$I_{0.5\%} = W/150 + 165(t)^{1/2} \qquad (12\text{-}4a)$$

and

$$I_{99.5\%} = W/150 + 495(t)^{1/2} \qquad (12\text{-}4b)$$

where

I_p = the current in microamperes that affects p percent of the population
W = body weight in pounds
t = time of exposure in seconds (5 s is maximum)

For leg-to-leg connections, there must be a current 10 times greater to achieve the same probabilities.

CASE 12-1

A school was setting up its stage for a special event in the auditorium. The stage decorations included fresh flowers and plants. There were to be two microphones on telescoping stands on the stage. There were receptacles on the stage floor to accommodate microphone plugs. Somehow, a plug for one of the microphones fell into the water in a vase containing one of the large flower displays. Later a worker inserted the plug into a microphone receptacle.

Another worker grabbed both microphone stands, one in each hand, to place them in the proper locations. Enough current flowed through the worker so he could not let go. As he struggled and called for help, someone else grabbed the worker using a nearby jacket and pulled him free from the microphone stands. The proper, quick response saved the worker, who was very shaken. An ambulance took the worker to a nearby hospital where tests determined there was no permanent damage to the worker.

Electric shock effects are a function of the resistance of the tissue involved in conduction. The resistance of the skin varies widely, depending on the moisture present from sweat or water. The resistance of wet skin is about 1000 ohms. Below the skin, the resistance of tissue is very low because it is essentially water or electrolyte.

High currents can burn tissue. Heating and arcing cause serious tissue damage. The areas of the skin that contact a conductor or where current enters or exits the body exhibit more serious tissue and burn damage than some internal tissue.

Heating and Fire

One of the leading causes of fires is electricity and electrical equipment. Many fires occur when currents flowing through conductors exceed their designed capacity, causing excessive heating that can ignite surrounding materials. Poor connections are another cause. As the contact areas between conductors become smaller, the current increases at the connections. This may increase temperatures at connections enough to cause parts to glow. Poor maintenance, vibration, abuse, physical damage, and other factors may cause electrical "shorts." This colloquial term refers to current passing through unintended routes or routes not designed to carry current. When there is very poor contact, arcing may result and may ignite nearby combustible materials.

Explosions

Arcing in the presence of an atmosphere containing combustible dust or flammable vapors may cause an explosion. Even low energy discharges of static electricity can initiate major disasters (see Case 12-2). Later chapters cover the principles of fire, combustion, and explosions.

Arc Flash

An arc flash[2] is the passage of current through air between conductors or between a conductor and neutral or ground. Conductive material may introduce an arc flash. An arc flash vaporizes conductor material. Temperatures can reach 35,000 degrees F and burn nearby workers or materials. The pressure wave from an arc flash, called an arc blast, can cause injury and physical damage.

Work involving potential arc flashes requires special planning and protection.[3] Work may involve standardized procedures including use of two-person teams. Restrict equipment access to authorized individuals at the room level and the individual equipment level. There should be warning labels on equipment with a potential for an arc flash. There should be lock out and tag out procedures to assure de-energized equipment. Authorized personnel should be trained on the equipment, hazards, controls, tools, personal protective equipment, work planning, and procedures.

12-3 CONTROL OF ELECTRICAL HAZARDS

There are a variety of controls that can reduce or eliminate electrical hazards. Groups of controls are physical controls, switching devices, grounding and bonding, ground fault

CASE 12-2

January 28, 2001, Elkin, NC. Eddie Adams, an electrician at an oriented strand board mill, attempted to service a 2300-volt starter. Apparently, he made bad procedural decisions that included trying to diagnose a failure using a volt meter intended for low voltages to test the starter. The starter exploded. The arc flash severely burned Mr. Adams. He died the next day.[a]

In 2012, Mr. Adams' co-workers produced a video that explains what happened and what protections he should have used. The group uploaded the video to YouTube in 2012.[b]

[a] *The Tribune*, Elkin-Jonesville, NC, January 18 and January 22, 2001.

[b] www.youtube.com/watch?v=hfnEuRA7-vo&feature+youtu.be

circuit interrupters, and procedures. Electrical hazard controls may also eliminate or reduce other hazards. The National Electric Code, the National Electric Safety Code, and other codes, regulations, and standards, provide detailed specifications and procedures for safeguarding electrical equipment and systems.

Physical Controls

Physical controls refer to materials used, design of parts, and placement of electrical equipment. Shielding, enclosing, and positioning of electrical devices can reduce contact with humans, other equipment, or hazardous materials and environments.

Wire Size and Length Equation (12-2) suggests resistance increases with the length of wire of a given cross-section or size. Also, the higher the resistance, the more the wire will heat when the current flows. Each gauge and type of wire has a recommended maximum length to limit its temperature and safe use.

Location When possible, place electrical equipment where people and other equipment cannot contact it. For example, poles keep power distribution lines out of people's reach and above most vehicles and equipment. Buried power lines reduce the likelihood of contact even further.

Shields, conduit and barriers need protection when distribution lines pass through or are in the "people" zone. For example, covers protect power lines extending from atop a pole to below ground. Locked gates and fences keep people, animals, vehicles, and other items out of power distribution substations.

Construction equipment, fire fighting equipment, and other elevated machines can contact overhead power lines. Equipment operators must know line locations and properly position equipment when working near lines. In some cases, the power should be shut off. Depending on voltage, electricity can arc through air as far as three or more feet to grounded equipment.

Conduit and Protective Coverings One of the reasons for placing electrical lines in metal conduits is to prevent physical damage to them. Another reason is to reduce the chance that people will contact energized conductors. The National Electric Code specifies the number of conductors, capacities, and other factors that determine the size of conduits and types of related fittings.

Nonconductive materials cover most electrical wires. There are a variety of protective materials and types of coverings. Protective materials have ratings for specific kinds of environments and conditions. Coverings may protect individual conductors, groups of them or both. A common example is extension cords which have light, medium, or heavy duty ratings. The rating does not indicate electrical capacity. The rating depends on the thickness and type of covering and indicates how well the cord can withstand physical abuse.

Sealed Equipment When someone turns a switch on or off, an arc may occur as the electrical contacts approach or separate. Similarly, electric motors arc as the brushes contact the commutator or slip rings. If an incandescent light bulb breaks, the filament will glow momentarily until it burns and breaks. When events such as these occur in an atmosphere containing a flammable mixture of air and gas or dust, a fire or explosion may result. To prevent this, there is special electrical equipment for use in hazardous environments. The electrical equipment (switches, motors, lighting fixtures, conduits, etc.) have seals to separate heat and sparks from the hazardous environment and to reduce the chance of physical damage. Electrical standards divide hazardous environments into classes and divisions. There are ratings for special electrical equipment that determine compliance with standards for each class and division. Table 12-2 gives a summary of hazardous location classifications.

Proper Connections There are many ways to connect electrical conductors: plugs, receptacles, screw terminals, wire nuts, and other special fasteners. It is important to tighten the screws or other fasteners that form electrical connections to ensure the conductors make good contact with each other. In some cases, codes specify the force or torque required for a connection. Over time, vibration, corrosion, creep of materials (see Chapter 10), damage, and other factors may reduce the connecting force. These

CASE 12-3

August 21, 2014, Campbellsville, KY. The local fire department participated in an "ice bucket challenge" charity event with the Campbellsville University band. The fire department positioned a ladder truck with a personnel bucket at the top above the band and sprayed the band members. Two firefighters were in the bucket.

As the firefighters began moving the ladder back, the bucket came close to power lines. Without touching the lines, there was a loud "boom" as an electrical arc flashed from the lines to the bucket. The two firefighters in the bucket received severe burns. One died a few weeks later. Two other firefighters on the ground who were at the controls also received electrical shocks. The event horrified band members watching from the ground.[a]

[a]www.nydailynews.com/news/national/ky-firefighter-injured-ice-bucket-challenge-dies-article-1.1946713

can reduce the contact area between conductors or between a conductor and a fastener. Unless the connections are tight and stay that way, the contact areas get smaller and current density increases, resulting in a connection heating and even glowing. In some applications, one should inspect connections from time to time to ensure they are tight and in good condition.

As noted in Chapter 10, creep was one problem with aluminum wire used in the late 1970s. An additional problem concerns corrosion. In contrast to copper oxide, aluminum oxide is not a good conductor. As aluminum wire corrodes, aluminum oxide forms on the wire outside surface. Resistance increases, producing more heat and accelerating corrosion. This problem may lead to fire. Aluminum creep and corrosion multiply the potential for these effects.

Isolation and Double Insulation Another form of physical control is separating energized portions of electrical equipment from those parts people can contact This is isolation. Several means can accomplish isolation. Covering conductors with nonconductive materials keeps people from contacting them. This is insulation. Another method is to provide two layers of enclosure for energized parts. At least one of the layers must be nonconductive and the nonconductive layer must separate a user from possible contact with any energized part. This is double insulation. Most portable power tools (drills, saws, etc.) have internal parts that cannot energize any portion of the external surface.

A person who works on electrical distribution lines sometimes stands on a rubber pad rated for the work being done. The pad is a form of isolation. It insulates the worker from other conductors so current will not pass through the worker's body.

Other equipment relies on isolation. Line worker's tools have nonconductive handles. Aerial baskets and their controls use nonconductive material to connect them to the lifting arm so current cannot pass through the basket. For cranes, there are devices that prevent current from flowing to the cab and chassis if the boom gets close to or contacts an overhead power line.

Overcurrent Devices

Overcurrent devices limit the current that can flow through a circuit or electrical device. If the current exceeds a given limit, the device shuts off power. Fuses and circuit breakers are two common overcurrent devices.

Fuses When placed in a circuit and if the current in the circuit exceeds some limiting value, the material in a fuse (usually lead or a lead alloy) heats above its melting point and separates. That stops the current flow. If the overcurrent is very large, it can damage parts in the circuit or equipment connected to it. The reason is the fuse heats and melts too slowly. Fuses come in various sizes and shapes for different purposes. They may protect very low current electrical circuits or large distribution lines. There are fast-acting and slow-acting fuses. Standards specify what types to use in specific applications.

Circuit Breakers Circuit breakers are a form of switch that opens when current passing through them exceeds some designed limit. There are two kinds of breakers, each with a different principle of operation. One type opens when the temperature of the breaker reaches a predetermined level. The temperature of the environment around the breaker can affect its response. The second type is magnetic. They open when reaching a predetermined current level. Environmental temperature has less effect on this type of breaker. There are many different breaker designs. Codes specify what types to use in certain applications.

Switching Devices

In addition to overcurrent devices, other switching devices can reduce or eliminate electrical hazards. They include lockouts, interlocks, and thermal or overspeed switches.

Lockouts Some switching devices use lockout devices and procedures. A lockout procedure involves placing a lock on a switch or other device to prevent turning on the switch or energizing the equipment. As illustrated in Figure 12-2, one kind of lockout device has holes for several locks. Each person working on equipment who can turn on the switch must place a lock through the lockout device. No one can open another person's lock and the switch will not operate until all persons remove their individual locks. A lockout procedure prevents someone from applying power who does not realize that another person is working on a circuit or its equipment.

Tagouts If a machine or item of equipment has a hazardous condition, a way to inform people is to place a tag on it that clearly identifies the hazard. That way, someone does not inadvertently use or work on the machine or item without knowing the danger. When working on electrical systems and equipment, workers need to use both lockout and tagout procedures concurrently. In addition, if equipment always has a known hazard, it may need a permanent label identifying the hazard.

Interlocks An interlock is a switch intended to prevent access to energized equipment or a dangerous location. Many access doors, panels, and gates have interlocks. When a door opens or someone removes a panel, the interlock interrupts power to enclosed equipment. Machine and equipment operator seats often have interlocks. When the operator leaves the seat, the switch cuts off power. In some applications interlocks

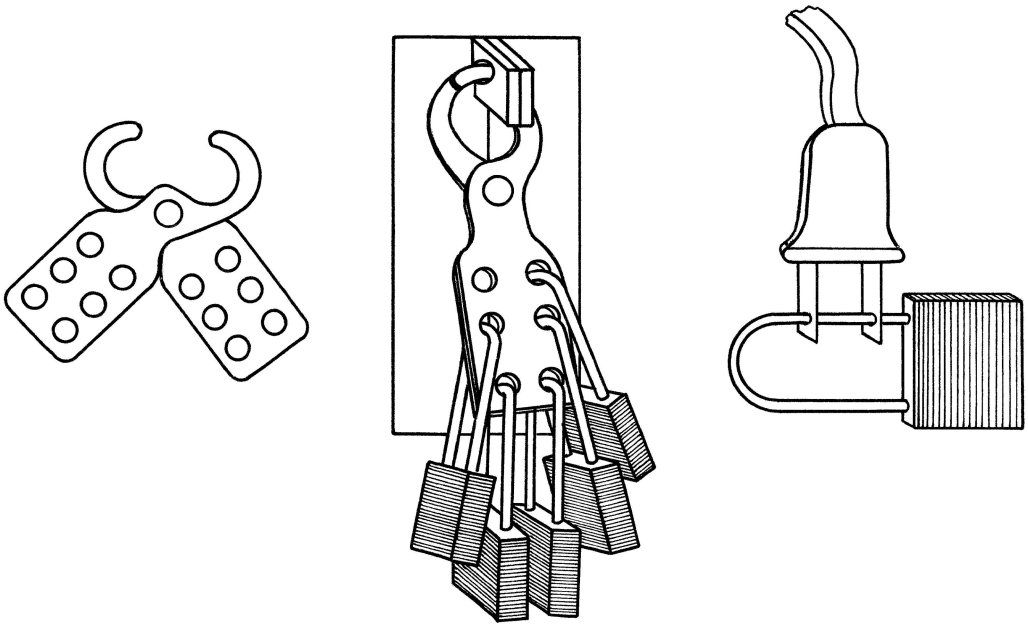


Figure 12-2. Examples of lockout devices.

fail to work because someone has removed or disengaged them. The equipment remains energized and in a dangerous condition. Another worker may not detect the hazard.

Thermal and Overspeed Cutouts The temperature of an electric motor will rise during use. If the temperature exceeds a certain value, a dangerous condition may exist. A temperature-sensitive switch with a preset temperature limit can interrupt power. Some electrical motors, equipment with resistance heaters (such as hair dryers), and other electrical equipment have thermal cutout switches.

There are many kinds of thermal switches. Some are normally open; some closed. Different switches have different preset action temperatures. Some operate one time, whereas others reset automatically after the temperature returns to a preset value. Others have a manual reset button.

Overspeed switches sense when a motor or other device operates too fast. Excessive speed may create dangerous conditions or indicate failure in the equipment. If a motor reaches excessive speed, the switch interrupts power to the equipment.

Grounding and Bonding

Grounding and bonding control the electrical potential between two bodies. If there is a difference in potential between two bodies, a conductor between them will allow charge or current to flow. That flow may be dangerous, particularly as a source of ignition.

Bonding In bonding, two bodies have a conductor between them. As illustrated in Figure 12-3(b), bonding equalizes the charge between the two bodies; it does not remove the charge from them. Bonding often controls static charge buildup. Bonding is not a protection from electric shock. A person can still become a conductor between a charged body and a ground.

Grounding In grounding, one or more charged bodies have conductors between them. The conductor connects to an electrical ground. Grounding removes charge from the bodies, as shown in Figure 12-3(c). Grounding usually involves driving a conductive rod (usually copper) into the ground and attaching ground connections to it. Electrical codes specify size and other requirements for ground rods and ground conductors.

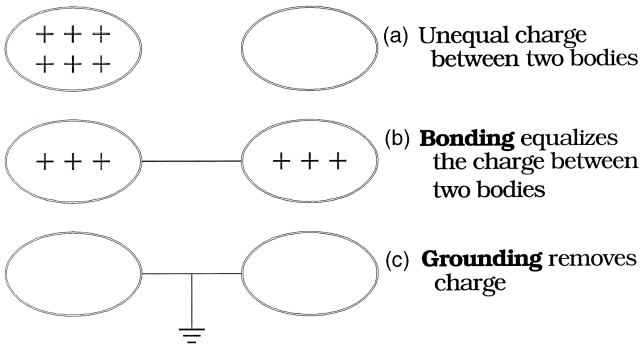


Figure 12-3. Grounding compared to bonding.

Grounding may protect people from electric shock. In 120 V electrical circuits an extra conductor connects electrical equipment that people may contact with a ground. Energized parts could shock someone who contacts them. However, the current will most likely flow through the ground wire, not through the person, so long as the parts connect to the ground wire.

Grounding of electrical equipment may not provide full protection. The ground connection from receptacle to ground rod may not exist or may have a break and that makes the ground connection to the equipment useless. If a device has a three-prong plug and someone has cut off the ground tab, the device is not grounded. Testing will determine the integrity of a grounding system. One type of low cost ground testing device plugs into a receptacle. Colored display lights tell if the ground works properly and if the polarity of the circuit is correct. Another type of instrument measures leakage current. The ground is not adequate if there is too much current leaking from the circuit.

Capacitors, chokes, and transformers retain electrical charge after cutting off external power. This charge will dissipate slowly and one cannot tell by inspection if the charge remains. In such cases, use a grounding or shorting stick or hook to discharge the energy. Because the tools will not remove all the charge at once, apply the tool several times to remove the charge. Some people leave a tool in place during work on equipment with charge storage devices.

Today, new 220/240 volt appliances, such as water heaters, dryers, and ranges, have four wires instead of three. Two are positive conductors, each out of phase with the other. A third is a neutral conductor and the fourth is a separate ground wire. Older appliances only had the first three wires.

Ground Fault Circuit Interrupter (GFCI)

Another means to protect people from electric shock is a ground fault circuit interrupter. A GFCI is a fast-acting circuit breaker that quickly senses very low current levels. Some GFCIs sense as little as 2 mA and shut off current in as little as 0.02 s. A GFCI compares current normally flowing through the power distribution wire and the grounded neutral wire of a circuit. The current flowing through one must pass through the other for the circuit to work. If the current is not equal, some electrical energy is flowing to ground through other than the normal route, perhaps through a person. When the current is not equal, the GFCI detects this current differential and shuts off the current.

GFCIs protect 110/120 V circuits where users can form a ground with energized equipment. GFCIs do not work on line-to-line connections found in distribution of 220 V and higher. The National Electric Code requires GFCIs for outdoor receptacles or circuits and for bathrooms and other locations.

Arc Fault Circuit Interrupter (AFCI)

An AFCI device is similar to a GFCI because it detects an electrical hazard and shuts off current to a receptacle or other device. An AFCI detects hazardous arc faults in an electrical circuit and deactivates it. GFCIs may be used concurrently with AFCIs.

AFCIs are similar to, but different from, GFCIs. The function of a GFCI is to protect people from the dangerous effects of electric shock when there is a ground fault in an electrical appliance or tool. The function of an AFCI is to protect branch circuit wiring from dangerous arcing faults that could cause an electrical fire.

Low Voltage

In confined spaces and wet areas achieving grounding protection for normal power may be difficult. Special low voltage equipment can reduce the electrical hazard. Some informally refer to this range of voltage as "safety low voltage." The special tools, lighting fixtures, power cords, and other electrical equipment operate using 24 VAC or less, limiting electrical energy levels. Isolation separates the "safety" low voltage power supply from its primary source at higher voltages. This special equipment may include additional safety features for other than electrical hazards.

Smart Power Integrated Circuits

An emerging technology involves combining microelectronics and power controls. Smartpower or power integrated circuits (PIC) can help reduce electrical hazards. These devices connect to a circuit and will have their own identification. The PIC will not permit current to flow to a device that it does not recognize. For example, this concept may prevent electrocution of a child who inserts a metal object into a receptacle.

Warnings

When there is a chance someone can gain access to energized electrical conductors and equipment, there should be warnings to indicate the dangers. The warning may take several forms, such as signs and visual or auditory warnings. Chapters 7 and 33 address the design and use of warnings.

Procedures

Work procedures for installation, use of, and maintenance of electrical systems and equipment can reduce risk. Procedures are different for high voltage power distribution, low voltage, and safety low voltage. Workers must learn these procedures. They must have proper tools and know how to use them. Electrical equipment for consumers must

have instructions that explain electrical hazards and how to prevent electrical injury.

First Aid Anyone working with electrical circuits and equipment should know rescue methods and first aid for electrical accidents. Too often attempts at rescue in electrical accidents result in a rescuer becoming part of the circuit and an additional victim.

Because respiratory arrest and fibrillation are common effects, knowledge of cardiopulmonary resuscitation (CPR) is essential for those who work with electrical circuits and equipment. Without immediate treatment for these injuries, chances of survival are minimal.

12-4 POWER GENERATION AND DISTRIBUTION

There are many forms of power generation, such as coal, natural gas, geothermal, solar, wind, water, and other fuel types. Each has some unique hazards. Various organizations offer guidance for these operations.[4]

There are special considerations in power distribution, such as specialized equipment, tools, personal protective equipment and procedures.[5]

12-5 STATIC ELECTRICITY

Physics

Electrical charge will build up when there is motion or friction between two insulated or partially insulated objects. The motion does not require rubbing or sliding. The likelihood of creating charge is usually greater when there are two different interfacing materials.

Many activities produce static electricity. A common experience is static buildup on one's body from walking on a carpet when the air is dry. A small arc occurs when a charged person touches another person or something at a different electrical potential. Belts moving over supporting rollers, sliding bulk material, the flow of fluids through pipes and hoses, and vehicle tires on pavements produce static charge. Static charge buildup is greater when the air has low moisture content. The amount of charge buildup and the release of charge at undesirable times and locations are the main concerns.

The amount of energy stored or discharged, E, through a spark or arc is

$$E = 1/2\,CV^2 \tag{12-5}$$

where

E is energy in joules

C is capacitance in farads

V is potential in volts

Capacitance is a property of a material. Capacitance for a person is about 100 pF. A walk over a carpet in dry air may produce as much as 50,000 V. According to Equation (12-5), a resulting spark would release 0.125 J.

Hazards

The main hazard of static electricity is creation of an arc and ignition of certain vapor or dust mixtures in air. Reference tables give minimum ignition energy for various mixtures. Chapter 17 discusses this hazard further.

Controls

One control is minimizing the buildup of charge. Using materials that do not generate or store as much charge as others can help. Bonding and grounding are the simplest ways to minimize charge buildup. Grounding is preferable because it removes charge. Humidification of air in closed environments may help, but is usually more costly and less effective in reducing risks.

Grounding or bonding wires reduce hazards during fueling operations, where someone transfers fuel from one container to another. Conductive floors reduce risks in hospital operating rooms, where anesthetic gases may be explosive under the right conditions. In locations where static charge from clothing could be dangerous, workers wear conductive clothing, particularly shoes. Clothing made from fabric that resists charge buildup or has antistatic chemicals can reduce risk. Conductive clothing, shoes, and flooring that control static charge may increase the hazard of electric shock from sources other than static charge.

There are instruments for measuring the presence and amount of static electricity. The instruments measure the electrical potential of charged objects or surfaces.

12-6 HOSPITAL PATIENTS

Medical patients may have equipment and instruments attached inside or outside their bodies. Small currents leaking from one instrument to another may be sufficiently large to cause injury or death. There are many ways a patient can become part of a circuit. A patient could reach out and directly contact equipment. Hospital staff could be in contact with electric equipment and touch a patient. Even a person cleaning the floor with a vacuum cleaner could create a leakage current hazard. A serious hazard exists when a patient has a catheter in or near the heart or has an electrical

connection attached to or near the heart during treatment, monitoring, or surgery.

A variety of techniques reduce the risk to a patient. Grounding and double insulation help. Isolation of circuits and sensor leads, minimal current for equipment operation, low voltages, and turning off unused equipment can all help. Shielding reduces magnetically induced currents. Some patient situations can become very complex, requiring special analysis to determine a safe solution. There are safe current limits and standards for the safe use of electrical equipment in hospitals and medicine. The American Association of Medical Instrumentation publishes a range of standards applicable to medical equipment.[6]

12-7 LIGHTNING

Lightning is the sudden release of static buildup in clouds, particularly during thunderstorms, which can produce very large currents. Lightning has occurred at nearly every location on our globe. However, there is a wide range in frequency of occurrence. Each year in the United States lightning kills about 150 people and property damage reaches millions of dollars. Lightning can cause external damage to property, such as structural damage, heating, and fire. It can cause internal damage to electrical distribution, communication, and data systems within a building.

A system of lightning rods or air terminals connected to a special ground rod is the normal method for providing external protection. A lightning protection system has air terminals placed strategically along roof lines, on protruding building elements (chimneys, dormers, etc.) or in the form of a protective grid. The air terminals intercept lightning discharges in their vicinity and conduct the current to the ground.

The most common internal protection is providing common grounding points for all systems in a building. Other means include the use of surge diverting or protection devices on electrical equipment, placing electrical equipment distant from lightning protection equipment, shielding of equipment and wires and use of stranded and twisted overcurrent protection.

12-8 BATTERY CHARGING, SHIPPING, AND STORAGE

Lead-Acid Batteries

Most automobiles, trucks, industrial vehicles, and other equipment depend on lead-acid batteries. These batteries can explode during charging operations, causing battery acid and particles from the case to injure the eyes or skin. Two types of explosions are possible: one related to flammability of hydrogen gas and the other electrical in nature.

During charging, lead-acid batteries produce hydrogen gas from the electrolytic fluid. If the hydrogen gas reaches a flammable concentration (4–75% by volume of air) in the air near the battery, a spark or flame can ignite it and produce an explosion. The arc may come from attaching or removing charging cables. An external heat or flame can come from a variety of sources.

The second type of explosion can occur when making connections. An explosion can occur if two connected batteries have different voltage or when joining terminals of differing polarities.

To prevent the first type of explosion, dilute the air around the battery with uncontaminated air to keep hydrogen gas from reaching an explosive concentration. An enclosed battery charging room needs an exhaust system. Charging rooms must have charging racks, and special coatings on walls and floors are desirable to prevent acid damage. Charging rooms should have an emergency eye wash fountain and emergency shower. Workers must wear protective eyewear and other protective clothing.

To prevent the second type of explosion, make sure batteries have the same voltage before connecting them. Connect negative terminals to a ground last (for cars that have a negative ground) and disconnect them first. Also, one should wear protective eyewear during this operation.

Other Batteries

There are a variety of batteries beside lead-acid batteries. Each has its own hazards. Large capacity, rechargeable batteries continue to be developed for automobiles, airplanes, and other applications. It is not possible to review the hazards and controls of each type. For some, performance issues require additional study.

EXERCISES

1. A worker was using a metal rod to unclog a spout at a grain elevator. The rod accidentally contacted a 7200 V power line. The worker suffered burns and other injuries that resulted from a fall. Estimate how much current was flowing through the worker's body. Assume a skin resistance of 80,000 ohms.
2. An operator of a boom crane became part of a circuit when the boom touched a 12,000 V power line. Assuming a skin resistance of 18,000 ohms, how much current flowed through the crane operator's body?
3. Soy protein dust requires 0.06 J for ignition. A belt moving the material has a capacitance of 300 pF. How many volts of electrical potential must accumulate on the belt to reach sufficient energy for ignition?

CASE 12-4

January 7, 2013, Boston Logan Airport. Late in 2012, the Boeing Company introduced the 787 Dreamliner into commercial service. It was a new aircraft that implemented many new design features. One feature was an onboard electrical support system using lithium-ion batteries.

A Japan Airlines 787 sitting on the ground at Boston's Logan Airport without passengers experienced an onboard battery fire. The National Transportation Safety Board investigated the incident. While the investigation traced the origin of the fire, the agency could not identify the root cause.[a] There was short-circuiting in a cell that led to thermal runaway, an uncontrolled chemical reaction that results from overheating that cascades to other cells and leads to fire.

A fire on board an aircraft is a serious hazard to anyone on board. A few other incidents in the 787 aircraft followed. Boeing developed changes to the system based on further studies and tests.

Several recommendations resulted. But there was no clear, comprehensive solution for the advanced battery technology.[b,c]

[a] www.ntsb.gov/investigations/2013/boeing_787/boeing_787.html

[b] www.ntsb.gov/doclib/recletters/2014/A-14-032-036.pdf

[c] www.isasi.org/Documents/library/technical-papers/2013/ISASI%20NTSB%20Kolly.pdf

4. Workers attached each leg of a 150-lb hospital patient to a different monitoring device. Both devices have 120 V, 60 Hz power supplies. How much current must pass through the patient to produce fibrillation at a 99.5% probability level?

5. A copper wire will supply current to a 2500 W electric space heater. The supply is 110 V, 60 Hz. What is the resistance of the heating device?

6. A copper wire supplying the heater in Problem 5 will be 6 ft long. What gauge is required if the resistivity must stay below 1.5 ohms/1000 ft to prevent excessive heating of the wire?

7. **(a)** Study the airline, manufacturer, NTSB, and FAA investigations, conclusions and actions taken for use of lithium-ion batteries commercial aircraft. Summarize your findings.

(b) Determine if there are also actions taken for shipping lithium-ion batteries on aircraft.

8. Review the kinds of batteries used for electric automobiles. Identify the effectiveness and hazards of each kind. Identify the risks associated with owner recharging equipment and procedures.

REVIEW QUESTIONS

1. State Ohm's law.

2. What are the following?:

(a) current density

(b) resistivity

(c) conductivity

3. How are resistivity and conductivity related?

4. State Joule's law.

5. Explain what may cause an electrical conductor to heat up.

6. What causes arcing?

7. What are the four main hazards of electricity?

8. What electrical characteristics contribute to the danger of electrical shock?

9. Which electrical parameter is most associated with the likelihood of shock?

10. How does electricity cause fibrillation?

11. What characteristic of skin most affects its electrical resistance?

12. What causes the "can't let go" phenomenon in electric shock?

13. How does electricity cause fires? Explosions?

14. What is an arc flash? Arc blast?

15. What are the main types of controls for electrical hazards?

16. Name five physical controls for electrical hazards.

17. What are the two kinds of overcurrent devices?

18. Name three kinds of switching devices. What does each protect against?

19. How do grounding and bonding differ?

20. Explain how a GFCI works. Explain how an AFCI works.

21. What does a GFCI protect? What does an AFCI protect?

22. Explain one way a PIC reduces electrical hazards.

23. What is the hazard of static electricity? How can it be controlled?

24. What special electrical hazards do medical patients face?

25. How is external protection from lightning achieved? Internal protection?

26. What are the hazards in charging lead-acid batteries? What are some controls?

NOTES

[1]R. H. Lee, "Human Electrical Safety," in *Electrical Safety Practice*, Monograph #110, Instrument Society of America, Research Triangle Park, NC, 1965.

[2]www.youtube.com/watch?v=Hp1JdVwbN_U; www.youtube.com/watch?v=P35HRYHFz7c

[3]www.osha.gov/dte/grant_materials/fy07/sh-16615-07/arc_flash_handout.pdf

[4]www.osha.gov/dep/greenjobs/index.html

[5]www.osha.gov/SLTC/powergeneration/construction.html; *Safety of Electrical Transmission and Distribution Systems*, UFC 3-560-10 N, www.wbdg.org/ccb/DOD/UFC/ARCHIVES/ufc_3_560_10n.pdf

[6]www.aami.org/publications/standards/

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CHAPTER 13

TOOLS AND MACHINES

13-1 TOOL AND MACHINE HAZARDS

Since the beginning of time, tools have extended human capabilities. Over time, tools became more sophisticated. The industrial revolution combined different tools into machines. A variety of power sources have improved the efficiency of tools and machines. Tools and machines using manual and other sources of power are more common than ever. There are many special kinds of tools that are often similar in function or action but specific to certain operations or materials.

Tools and machines are a major source of injuries. Hand tools cause about 8% of lost-time occupational accidents; machines cause an even greater share. Because powered tools and machines involve high levels of energy and power, injuries are often more severe than for hand-operated ones.

Hazards

There is a variety of hazards associated with tools and machines. Some hazards are unique to particular tools and machines, other hazards relate to the material acted on or the use environment. Certain hazards are common for many kinds of tools and machines.

Being struck by a tool, moving machine or machine part is one hazard. For example, most everyone has struck a finger or thumb when learning to drive a nail with a hammer. Motor vehicles, one type of machine, strike people every day.

Being struck by materials is another hazard for some tools and machines. When using a cold chisel or star drill and hammer to break a hole in concrete, particles of concrete fly from the tip of the tool with each blow. Particles fly from the cutting tool as a lathe removes material. The particles may strike the tool or machine user or someone else. Some parts of the body, such as the eyes, have a greater risk of injury than others when struck by flying materials.

Another kind of hazard is getting caught in a machine or tool. Many people have experienced the pinching action of a pair of pliers. One can get caught in many ways. Power transmission elements, such as belts, chains, gears, linkages, shafts, and other components, have pinch points or catch points. In many machines and tools there are dangers at the points of operation.

Repeated motion by users operating a tool or machine can lead to a group of injuries called cumulative trauma disorders or repeated motion disorders (RMDs).

The power source may add to the inherent hazards of a tool or machine itself. For example, electrical power brings certain hazards (discussed in Chapter 12). Combustible fuels, explosives, hydraulics, and pneumatics each bring additional hazard to the tools and machines they power. Machines and tools may create noise hazards, produce air contaminants, get hot, or create other hazards.

Injuries

There are many kinds of injuries related to tools and machines. Tools and machines designed to cut materials will also cut people. Knives, hatchets, and axes are examples of cutting action hand tools. Hedge trimmers, paper cutting machines, and shears are examples of powered tools and machines.

Abrasion injuries result from contact with machines that use friction or abrasion, such as grinding and sanding equipment. Puncture wounds can result from contact with pointed tools, like drills, punches, and awls. Tissue tears and cuts may result from contact with sharp edges on equipment.

A variety of crushing injuries, fractures, and other injuries can result from getting caught in the compression action of a tool or machine.

Flying particles may cause injuries to surface tissue upon impact. The likelihood of injury depends on the tissue struck, the strength of the tissue, and the ability of the tissue to absorb and distribute forces. The larger the material in motion, the greater the chances of injury. Initial impact may not be the only concern. The materials may have other hazards associated with them. For example, they may be caustic or they may be rough and cause injury if they contact skin or other tissue.

Objects may fall from machines and crush hands, feet or bodies. There may be poor anchoring of materials acted on by tools and machines. The materials subsequently fall, producing crushing or related injuries.

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Cumulative Trauma or Repeated Motion Injuries

Ergonomics (see Chapter 33) addresses the interaction between people and equipment, workstations and buildings. One role for ergonomists is preventing injuries through design.

Cumulative trauma injuries, cumulative trauma disorders or repeated motion injuries are a family of injuries that result from repeated motion or repeated use of a tool or other equipment. Most involve inflammation of or damage to various tissues. Several may occur at the same time. The appearance of symptoms will vary from person to person, with frequency of activity, forces, and movements involved in the activity, and other factors. Factors other than repeated motion, such as age and personal differences, may contribute to the incidence of these disorders.

Trigger Finger Irritation and soreness of the hand resulting from repeated use of individual fingers for operation of switches and buttons characterize trigger finger. Operation of spray guns, video games, power tools, or machine controls with one or more fingers may result in trigger finger.

Carpal Tunnel Syndrome This is an affliction caused by the compression of the median nerve, median artery, and tendons passing through the carpal tunnel of the wrist (see Figure 13-1). The medial side of the wrist has a ligament band that serves as a "pulley" of sorts for the tendons extending from muscles in the forearm to the fingers. The size of the passage under this band may decrease from inflammation, aging, and other factors. Extreme bending of the wrist, particularly ulnar deviation, causes tissues in and surrounding the carpal tunnel to become irritated and swell. Symptoms of carpal tunnel syndrome include tingling, pain or numbness in the thumb and first three fingers, and reduced manipulative skills in the hand.

Raynaud's Syndrome This disorder, also called white finger, results when blood vessels in the hand constrict from cold temperature, vibration, emotion, or unknown causes. Signs and symptoms include both hands becoming

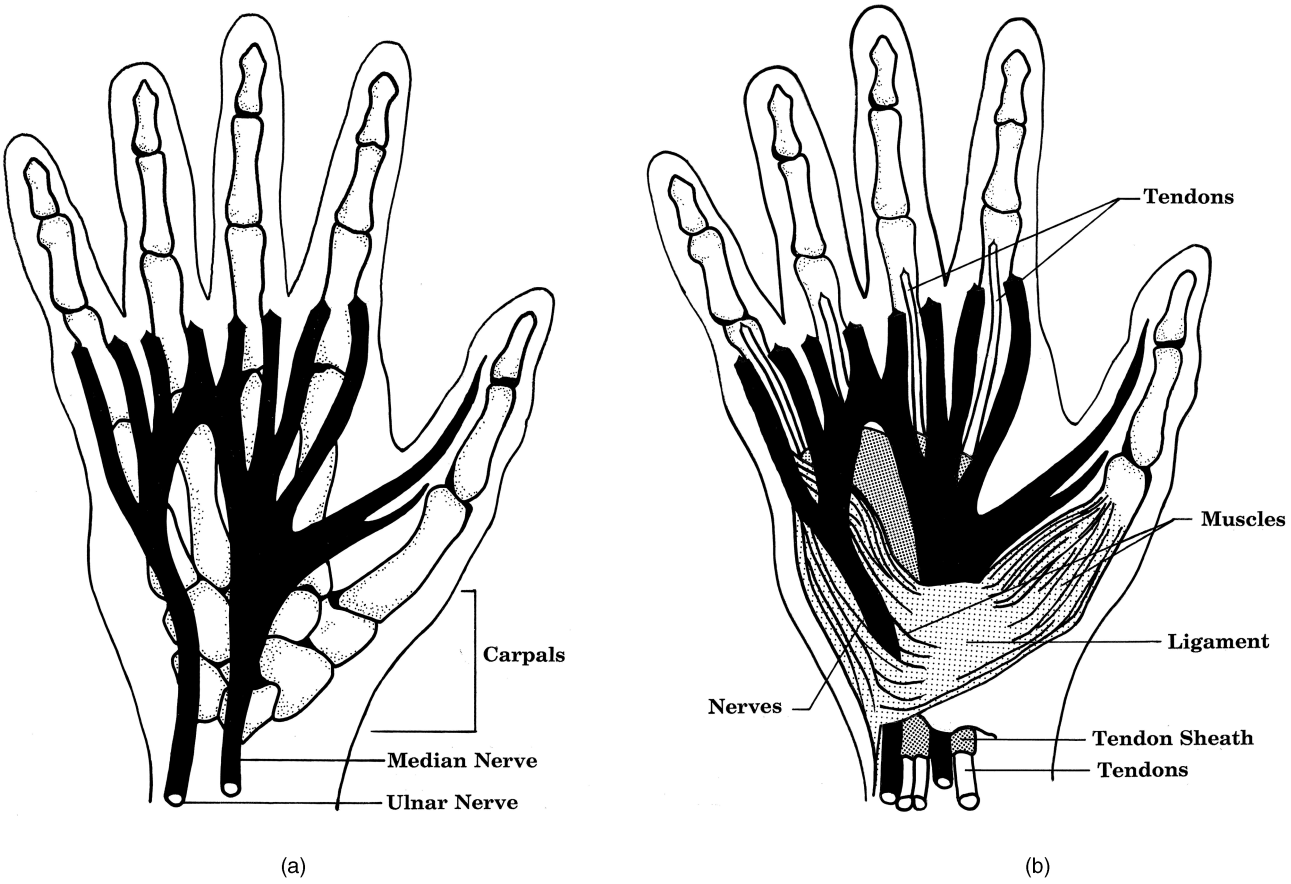


Figure 13-1. Pictorial representation of the anatomy related to carpal tunnel syndrome. Nerves both left and right views), blood vessels (right view), tendons and tendon sheaths (right view) pass through the carpal region of the wrist. The large ligament over the carpal region helps keep tissues in place during wrist articulation. Various forms of inflammation and disorders in the wrist and hands can result from repetitive motions.

simultaneously cold, blue, or white and numb, and loss of manipulation of fine objects. Upon recovery, the hands become red, accompanied by a burning sensation. Of particular concern in design of tools and controls for machines is vibration that induces Raynaud's syndrome. The handles on some machine and tools may produce very high compression forces on the tissues of the palm and lead to this disorder. Examples of activities that lead to Raynaud's syndrome are use of impact tools and vibrating sanders.

Dequervain's Disease This disorder results from narrowing of the tendon sheath for both long and short abductor muscles of the thumb. This disease results from manual tasks involving radial or inward hand motions and firm grips.

Bursitis Each joint of the body has an encapsulating tissue called the bursa. Bursitis is the inflammation of the bursa.

Tendinitis Tendinitis is inflammation of a tendon.

Perimyotendinitis This disorder is the inflammation of tissues surrounding a tendon or its sheath.

Tenosynovitis, Stenosing Tenosynovitis, or Tenovaginitis These terms refer to inflammation involving the compression or narrowing of a tendon sheath.

Epicondylitis This disorder results from the combined action of pronation of the hand and ulnar deviation. For example, swinging a hammer involves this combination of motions. Symptoms include pain in the elbow, forearm and hand. Epicondylitis also has activity-related names, such as carpenter's elbow or tennis elbow.

Ganglion Cysts This disorder is the enlargement of a nerve cell or ganglion. The disorder often appears with other cumulative trauma disorders.

Rotator Cuff This disorder stems from a tearing of a particular ligament in the shoulder joint. As a result, the mechanics of the shoulder change. Symptoms are having difficulty starting to raise an arm from a position along the side of the body or raising the arm above shoulder height.

Thoracic Outlet Syndrome This disorder stems from restriction of the blood supply or compression of the nerves passing from the neck to the shoulder. Symptoms may include lateral arm pain, tingling of the ring and small finger, and hand swelling or weakness. Activities contributing to this disorder include pulling the shoulders back and down or carrying heavy loads in the hand (such as carrying suitcases or similar objects). Other activities may involve working overhead with repeated arm abduction and adduction, and holding something between the shoulder and neck (such as a telephone receiver).

13-2 SAFEGUARDING MACHINES

History

Powered machines became prominent during the industrial revolution. With the growth of machine use, injuries resulting from machines increased. Principles of guarding closely paralleled the industrial revolution. Whereas machines, designs, and materials have changed, the principles of guarding have been around for a long time. Over the years, guarding principles and standards have appeared in many publications on machines. New technologies have provided some new capabilities for machines and added features. However, the basic ideas for guarding have changed little.

The U.S. Patent and Trademark Office issued the first patent for an interlock in 1868. The interlock was a mechanical arrangement. The agency issued the first electrical interlock on a power transmission guard in 1923. In 1899, the agency issued a patent for a press guard that prevented the machine from acting if the guard was not fully closed.

The earliest set of standards for machine guarding appeared in 1914. The current series of ANSI machine guarding standards (B11 series) began in 1922 with the adoption of the first standard for power presses and foot and hand presses. The first edition of the standard for guarding power transmission apparatus (B15) appeared in 1927.[1]

Types of Machine Motion

There are five types of machine motion (see Figure 13-2) that create machine hazards: rotation, reciprocating or transverse motion, in-running nip points or pinch points, cutting actions, and punching, shearing, and bending.

Rotation One example of rotating motion is the spindle, chuck, and bit of a drill. Others are shafts, splines, couplings, feed stock, flywheels, and handwheels. Burrs, set screws, keys, rough surfaces, and rotary or eccentric motion all tend to catch clothing or hair. Even smooth, rotating surfaces can catch clothing, hair, or other loose material and wind it up. Once caught, clothing or hair quickly pulls a person into a machine. Skin contact with these moving surfaces can also produce injury from abrasion.

Reciprocating or Transverse Motion Back and forth motion and motion in a straight line are dangerous because someone may be in the line of motion. The moving part of the machine may strike the person. Someone could also get sheared or pinched between fixed and moving parts of the machine or between the moving part of the machine and a surrounding fixed object.

Consider the body of a crawler-type back hoe in motion. It can create a shear or pinch point when operated near a short concrete wall. When the crawler body faces

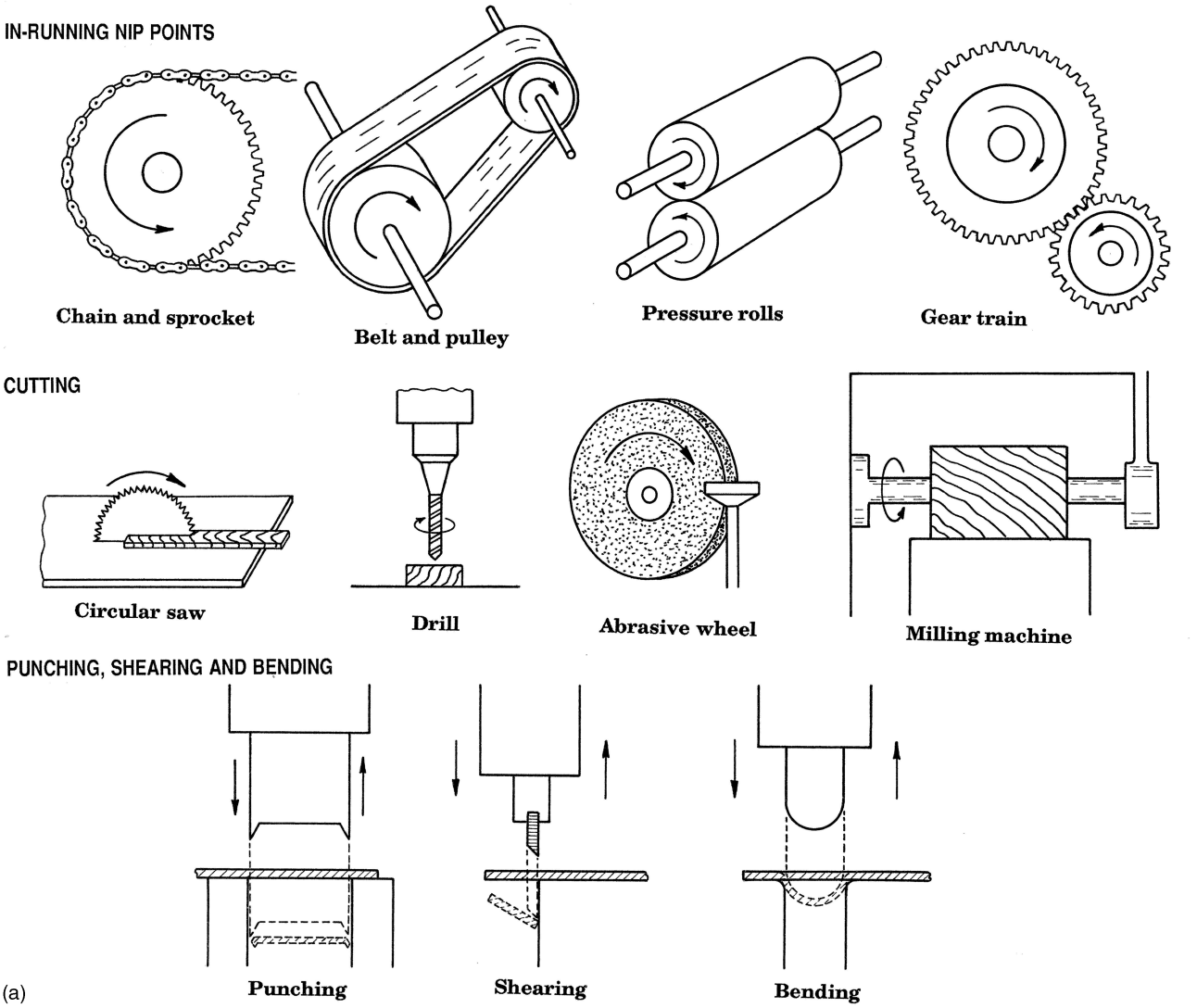


Figure 13-2. Five types of machine motions and examples of each.

forward, the rear of the body may have clearance from a wall located alongside. When the crawler body rotates to the side, the rear of the body may extend over the top of the wall and crush someone against the wall.

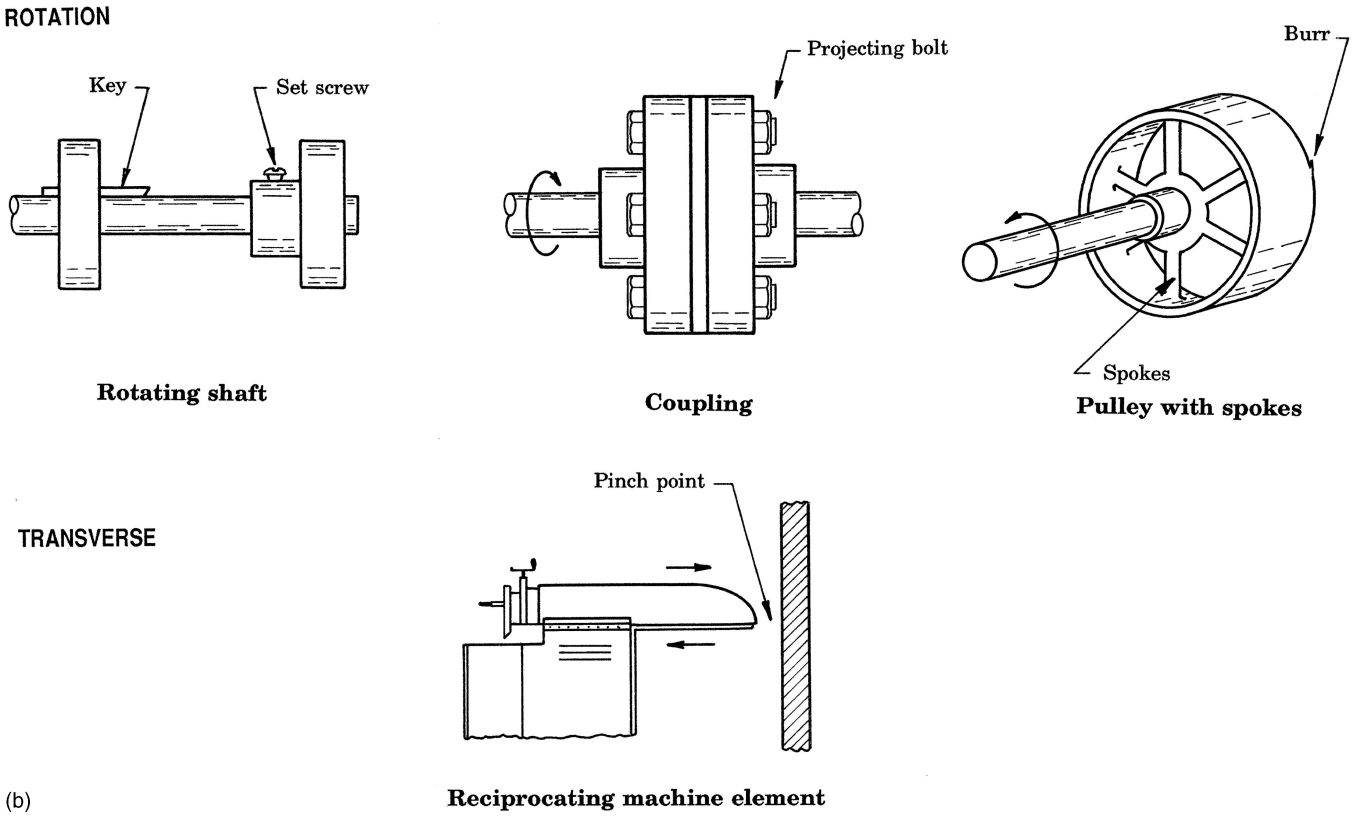
In-Running Nip Points Machine parts that rotate toward each other or rotate toward a fixed component create in-running nip points or pinch points. If these pinch or nip points catch someone, severe injury might result. Examples of in-running nip points are belts and pulleys, chains and sprockets, gears, conveyor belts and rollers, and rolls used for various forming, mixing, and processing functions.

Cutting Actions Machines that cut or remove material have cutting actions. Examples are saws, milling machines, shaping and planing machines, lathes, grinders, and boring mills. If the machine can cut wood, leather, metal, or paper, it can cut human tissue. The location of a machine's cutting action is the point of operation.

Punching, Shearing, and Bending This type of motion describes two machine components that come together. Both may move or one may be fixed. Examples of this motion are punching, shearing, bending, stamping, drawing, and trimming. If the machine can perform these functions on metal, paper, wood, or other material fed into it, it can also damage human tissue. Again, the danger is at the point of operation.

Types of Safeguards

Safeguards include guards, devices, distance, or location. Safeguards for machines fall into two major groups: mechanical power transmission safeguards, and point-of-operation safeguards.



(b)

Figure 13-2. *Continued*

Guards Guards are barriers that prevent the entry of a person's body and clothing into a hazardous part of a machine. They also prevent materials from striking and injuring someone.

Devices Devices are controls or attachments that inhibit normal operation of a machine if any portion of a person's body is within a hazardous area.

Distance Distance places the hazardous portion of a machine vertically or horizontally out of reach to prevent inadvertent contact with or access to a dangerous part.

Location Location means placing a hazardous machine or component where people will not normally be.

Guarding Principles

A guard is one type of machine safeguard. Guards are preferable to other safeguard types. Guards on machines intend to keep people and their clothing from coming into contact with hazardous parts of machines and equipment. They also prevent flying particles from an operation and broken machine parts from coming into contact with or striking people. Guards may serve other functions, such as enclosing noise or dust and forming part of an exhaust system.

Guards must have various characteristics. They must be a permanent part of the machine or equipment. They must prevent access to the danger zone during operation. They must be durable and constructed strongly enough to resist the wear and abuse expected in their use environment. Guards must not create hazards. They should not interfere with operating the machine.

CASE 13-1

October 9, 2014, Cincinnati, OH. The Occupational Safety and Health Administration issued a citation to Kloeckner Metals Corp. for failure to guard an in-running nip point on a machine with rollers that moved materials into the machine. On April 22, 2014, a worker got caught in the machine action and suffered severe injuries. The citation included a repeat violation because the company had received a similar citation the previous year. The citation included penalties of $56,000.[a]

[a]www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=26847

CASE 13-2

January 15, 2009, Syracuse, NY. Jack Grobsmith died in an accident at the Crucible Specialty Metals steel mill that compressed hot steel through rollers. While helping to get the mill into operation on a very cold morning, Mr. Grobsmith was connecting a water hose to part of the machine. Next to him were rotating shafts driven by a 900-horsepower motor that turned the shafts at 240 rpm. While struggling with the hose, Mr. Grobsmith slipped. The shafts pulled him in, crushed him and shot him out the other side.

After completing an inspection following the fatality, OSHA cited the company for more than 70 violations and issued $250,000 in fines. The company filed for bankruptcy. A private equity company purchased the company. The company never paid the fine.[a]

[a]www.publicintegrity.org/2012/12/21/11945/even-after-workplace-deaths-companies-avoid-osha-penalties

Maintenance and Cleaning Some guard designs protect machine users only during normal operations. Where possible, designs should provide protection during routine inspection, adjusting, lubricating, cleaning, and repairing without removing them. Because the equipment will probably pose the same hazards during setup, maintenance and repair, guards should protect these activities as well.

Guard Openings Guards may have openings for several reasons. Machines users must insert materials into machines for processing. Openings may allow for inspection or lubrication and to monitor machine action. The larger an opening, the farther someone can reach through it.

About 1950, the insurance industry studied the relationships between opening size and the distance one can reach through an opening. The resulting relationships appear in Table 13-1 and Figure 13-3. These data define how far to place a barrier from a danger point for certain sized openings. A danger point or line is where the dangerous action of a machine occurs. A danger point is also a machine action location narrowing to 3/8 in. That dimension or a smaller one defines a pinch point. The definition recognizes that small fingers are about three-eighths of an inch thick. Figure 13-4 illustrates the danger line for openings between rollers and the application of distance-opening data. For rollers that have openings greater than 3/8 in., the fingers and hands may not sustain severe crushing. Not only are straight line distances important, but so is the potential of reaching around or over some obstacle. Figure 13-5 gives an example. In some cases one also must use human anthropometric data (see Appendix A and other sources) to determine if people can reach into the hazardous part of a machine.

TABLE 13-1 Distances a Guard Must Be from a Danger Line for Various Sizes of Openings

Distance of Opening from the Danger Line (in.)	Maximum Width of Opening (in.)
½ to 1½	¼
1½ to 2½	$\frac{3}{8}$
2½ to 3½	½
3½ to 5½	$\frac{5}{8}$
5½ to 6½	$\frac{3}{4}$
6½ to 7½	$\frac{7}{8}$
7½ to 12½	1¼
12½ to 15½	1½
15½ to 17½	$1\frac{7}{8}$
17½ to 31½	$2\frac{1}{8}$

Guard Construction Guards must be substantial. To make them substantial, designers must consider the forces and events guards must withstand and the use environment for the machines and guards. The environment may be dusty. Vehicles dumping material may strike guards. In some cases the structural criterion is the force of a person leaning or falling on a guard. In other cases the force and energy of flying machine parts or materials will establish what is substantial. Environmental factors, like a constant shower of particulates, a corrosive mist or excessive heat, will determine what is substantial. Some standards give recommended materials of construction.

13-3 POWER TRANSMISSION SAFEGUARDS

Most machines use power transmission components to transfer power from a motor, engine or other prime mover to an element of a machine where a useful function occurs. Some common power transmission components are belts, pulleys, ropes, sheaves, chains, sprockets, gears, and friction rollers. Many of these components create pinch, nip, or shear points.

Rotating shafts and couplings are also power transmission components. They pose danger from their rotary motion. Some power transmissions include flywheels, which store energy during the power transmission process. At excessive speeds or after extended stress, they may fly apart. When not fully enclosed, people can come into contact with them.

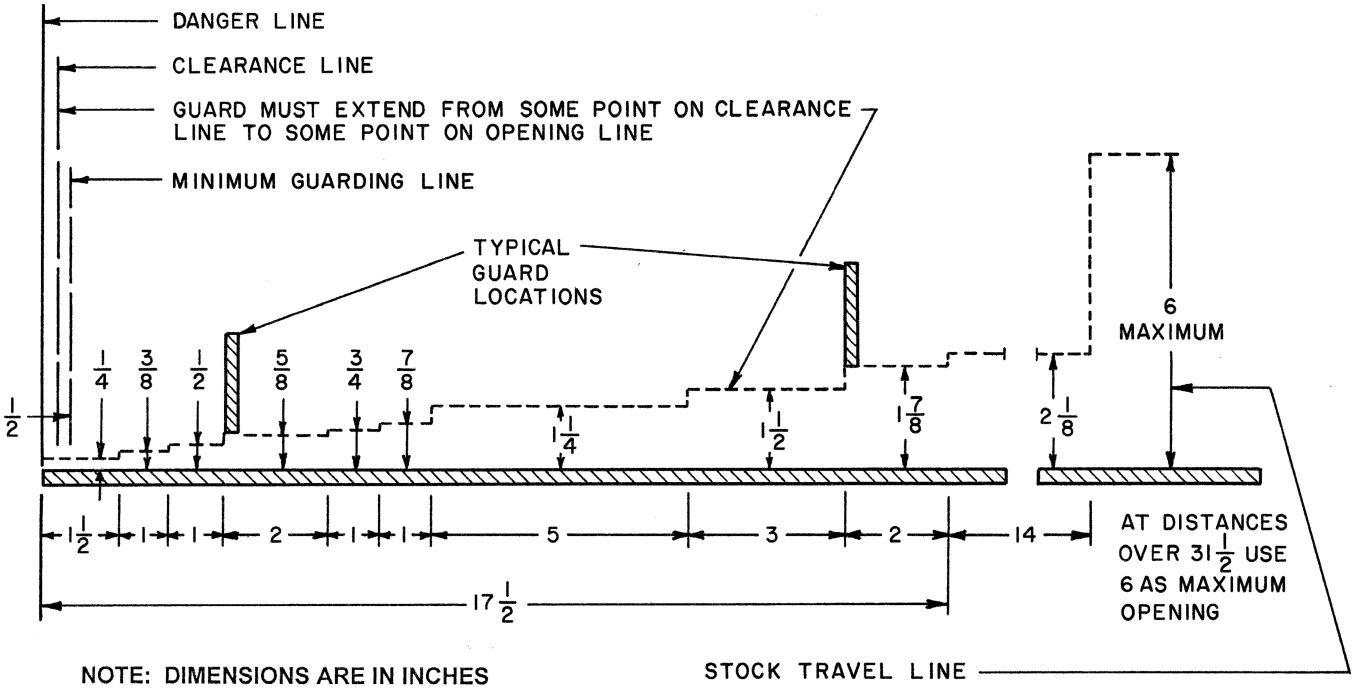
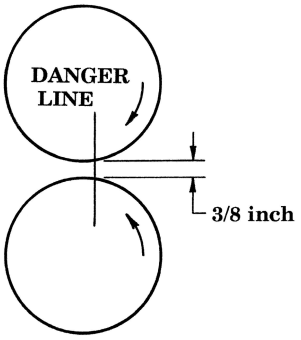


Figure 13-3. The distance guards must be located from a danger point depends on the size of the opening in the guard.



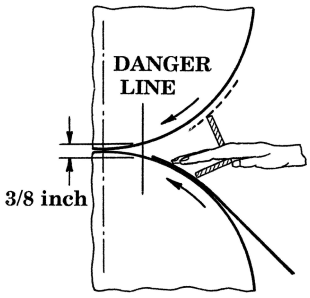


Figure 13-4. The danger line for in-running rolls is where the rolls are 3/8 in apart. The danger line determines the pinch point. The distance from the 3/8 in pinch point becomes the reference for guard placement.

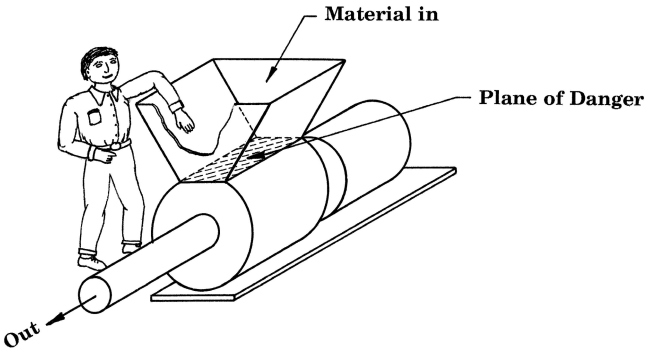


Figure 13-5. Example of using distance to keep someone from reaching into dangerous parts of a machine. Applications and various standards determine whether the use of distance provides sufficient protection.

CASE 13-3

March 17, 2014, Columbus, OH. The Occupational Safety and Health Administration issued approximately 26 citations related to machine guarding deficiencies against the ConAgra Foods Inc. flour mill in Columbus, OH. The citations identify there were ten serious violations, which have a substantial probability of death or serious harm to workers. Some violations were repeat violations, including similar violations in other ConAgra food plants. In the case, OSHA issued $117,000 in fines.[a]

[a]www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=25743

Power Transmission Guards

If possible, power transmission guards (see Figure 13-6) should totally enclose the hazardous components. They should prevent fingers, hands, or other parts of the body from coming into contact with them. Designs should prevent personnel from reaching around, over, under, or through the guard to the danger point.

Fasten guards to a machine to prevent access to the hazardous areas. Guards should have one or more interlocks that will de-energize the machine when someone removes the guard. When possible, guard designs should allow personnel to lubricate, adjust, and inspect a machine from outside the guard without removing it.

Devices

If a guard has an access panel, the panel should have an interlock or presence sensing device that will de-energize the machine or some enclosed power transmission equipment. There should be an emergency shutoff control within reach of the hazardous components for every operator. This is necessary in case someone does get caught after removing a guard or there is an opened access panel on an energized machine.

Distance and Location

Mechanical power transmission equipment that is out of reach of people may not require guards. Various standards set the minimum distance required from a floor or walking surface to overhead mechanical power transmission apparatus. The minimum distance is often about 8 ft. Most people would not be likely to contact or reach above this distance. Anthropometric reach data can also establish safe distances from people to danger points. Distances to danger points within reach require guarding. There may be overhead or enclosing screens, walls or fences that create safe locations. These barriers must be permanent and substantial. Only trained workers should have access to the enclosed locations.

If there is overhead protection for conveyors and belts that prevents items from falling on workers below, the protective barrier should be strong enough to stop the falling items. If workers must climb to the barrier to remove fallen

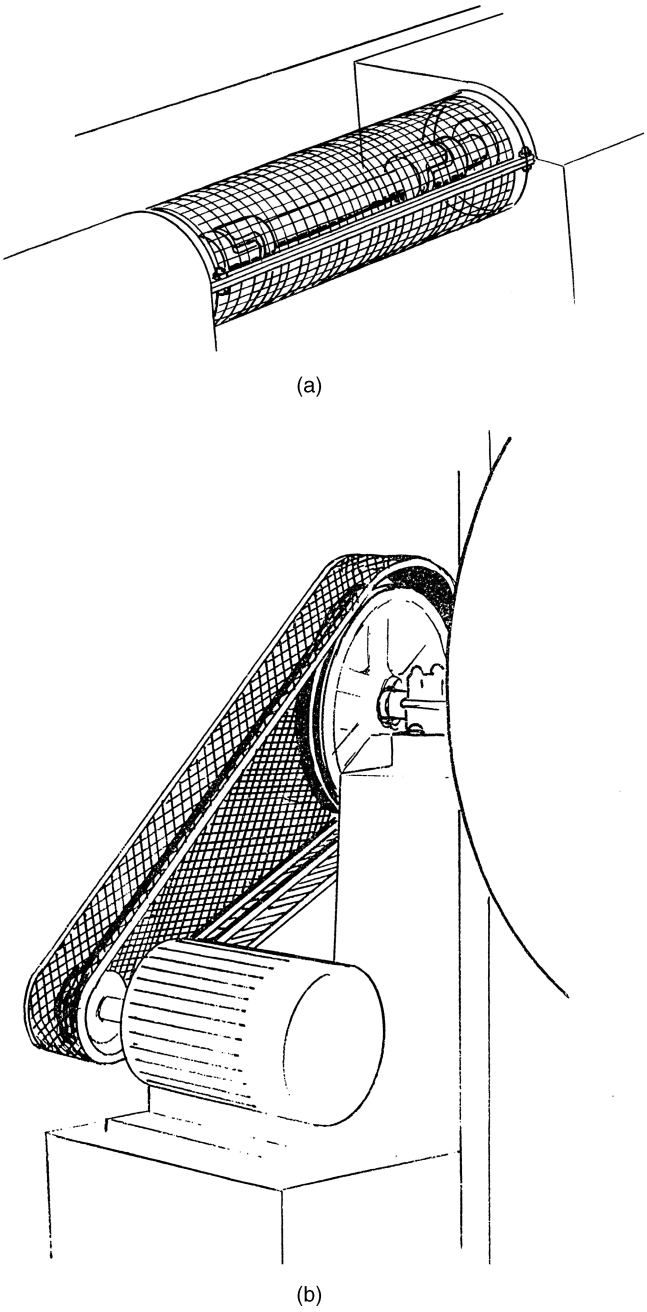


Figure 13-6. Examples of power transmission guards. (From *MSHA's Guide to Equipment Guarding*, 1980.)

CASE 13-4

Two men operated a tree removal service. After cutting down a tree, they removed the branches from the trunk. Then they started feeding tree branches into a chipper pulled behind their dump truck. One man inserted a sizeable branch into the infeed hopper of the chipper. However, the branch caught the sleeve on his shirt and began pulling him into the hopper. He yelled to his partner. Neither the operator nor his partner could stop the operation quickly because the chipper had no emergency shut-off switches on the hopper. By the time his partner got to the main controls on the engine, the first operator had lost an arm.

materials, the barrier must be strong enough to support the weight of the workers.

Warnings

Guards and access points to hazardous areas of power transmission components should have warnings. The warnings should tell people to de-energize, lockout and tagout power before opening the access or removing a guard.

Openings

Openings in power transmission guards, partitions, or screens must prevent people from coming into contact with hazardous elements. Such openings must comply with data in Table 13-1 and Figure 13-3.

13-4 POINT-OF-OPERATION SAFEGUARDS

A point-of-operation is the location where a machine performs work. Although there are many kinds of machines, each performing a different function, the basic kinds of machine motions previously described cover them all. The safeguards for points-of-operation include guards, devices, tools, awareness barriers and signals, and emergency stop controls. Not all of these safeguards apply to every machine. Standards, manufacturers' manuals and references for particular machines will give more details and identify suitable safeguards.

Guards

Enclosure Guards Point-of-operation guards (see Figure 13-7) should prevent fingers, hands, other body parts, and clothing from reaching through, under, over, or around the guard to the point-of-operation. Criteria in Table 13-1 and Figure 13-3 apply. Attach a guard to the machine so it does not create additional hazards. Construct and attach guards with fasteners that require tools to remove them. That helps prevent unauthorized removal. Most guards should permit viewing the point-of-operation.

Interlocked Guards In some cases guards have a hinged or moveable section for setup, adjustment or maintenance. In other cases, these activities require removal of a guard. There should be interlocks that stop the machine motion upon removal of a guard or a portion of it. That prevents the machine from operating. Figure 13-8 gives one example of a guard interlock.

Adjustable Guards Some guards need adjustment for different operations (see Figure 13-9). Adjustable sections should meet other guarding requirements.

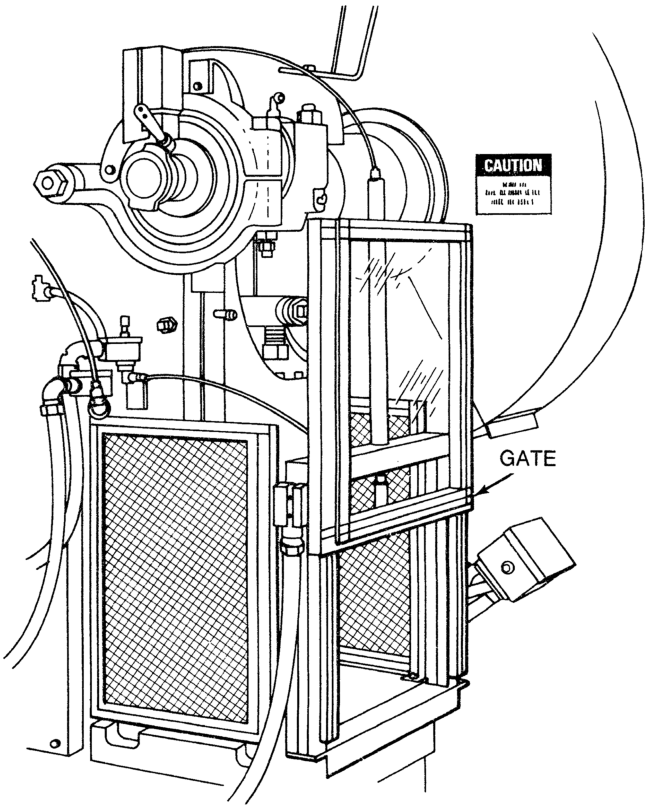


Figure 13-7. Example of an enclosure guard. (From OSHA 3067.)

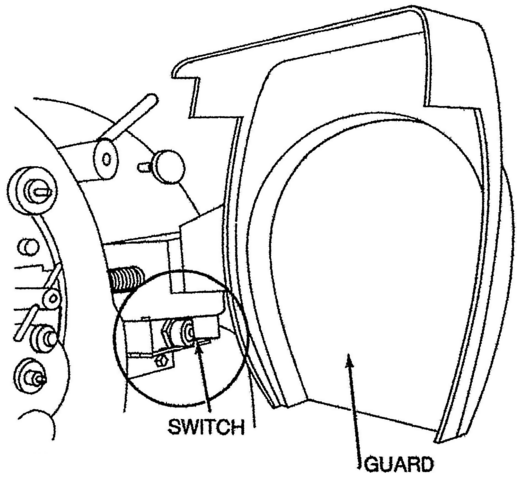


Figure 13-8. An example of an interlock. (From OSHA 3067) Opening the hinged guard activates the microswitch to interrupt power to the machine.

Special Guards There are many special guards (see Figure 13-10) that are unique to particular machines or machine actions. A few examples illustrate some of these special problems.

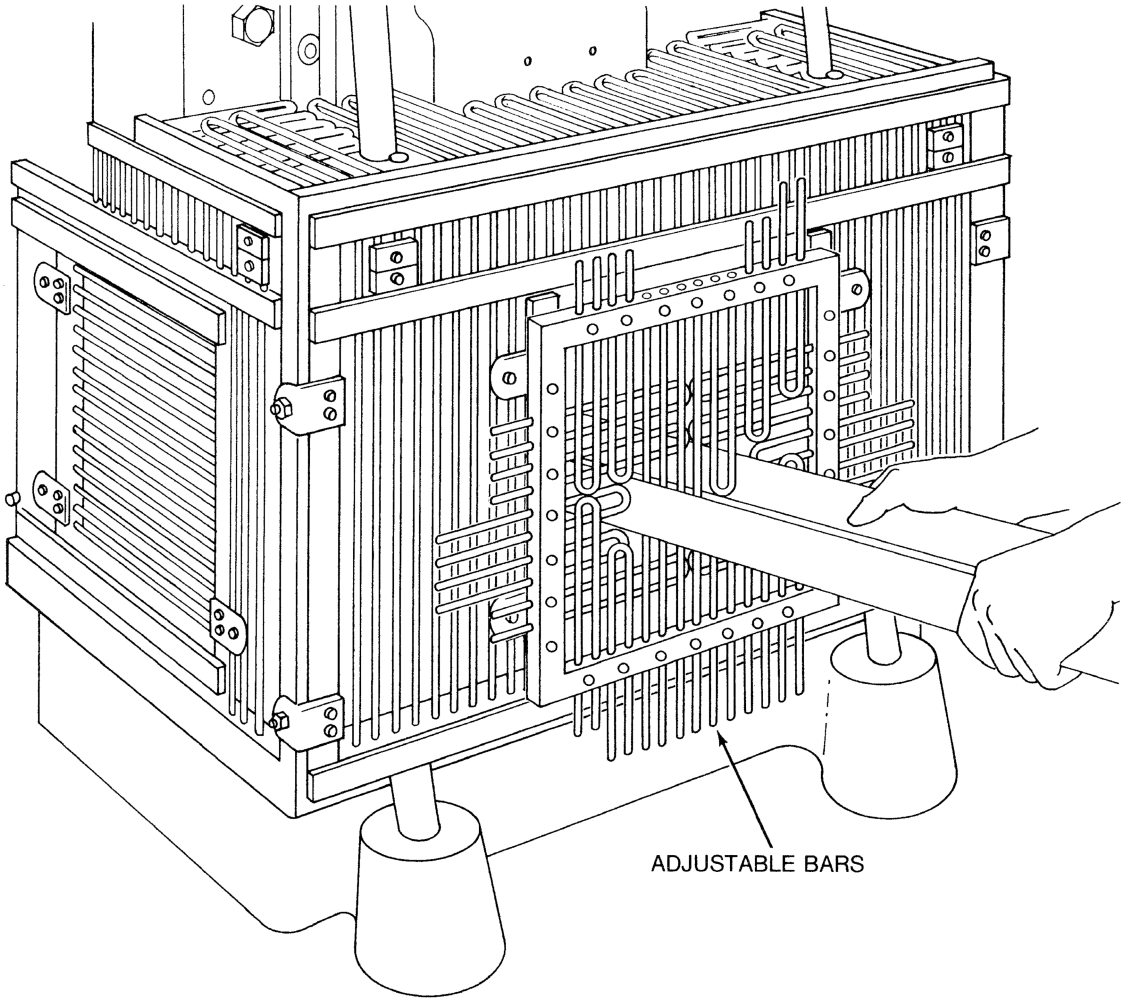


Figure 13-9. Example of an adjustable guard. (From OSHA 3067.)

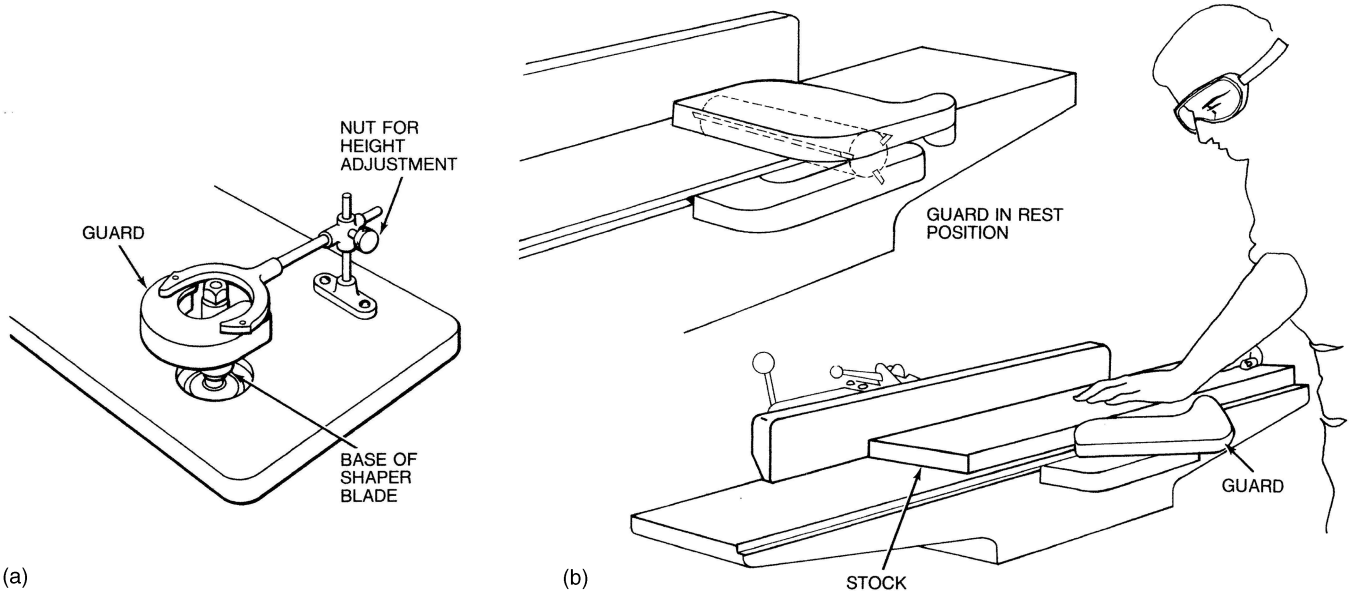


Figure 13-10. Examples of some special guards: (a) ring guard for a shaper, (b) leg of mutton guard for a jointer. (From OSHA 3067.)

Ring Guard All sides of a rotating cutter on a shaper are exposed. A ring guard surrounds the cutter. A ring guard adjusts to allow material to pass under it and provides protection from the remaining exposed portion of the cutter.

Leg-of-Mutton Guard A leg-of-mutton guard covers the cutting head of a jointer. It gets its name from its shape. It swings horizontally out of the way when wood material moves across the jointer table. Its position varies with adjustments made in the fence that guides the material. If the fence exposes the cutter on the non-operational side, the part of the cutter behind the fence requires guarding as well. Because a leg-of-mutton guard can only move horizontally, it will not protect all jointer cuts. Other guards float vertically and give protection as material moves over the cutting head.

Hood Guard Circular table saws typically have a hood guard over the blade. The guard floats vertically as material moves under the guard and into the blade.

Grinding Wheel Guards Guards for grinding wheels perform several functions. They help keep operators from coming into contact with the wheel itself. They help contain fragments should a wheel fracture, disintegrate and fly apart. As a result, grinding wheel guards have much heavier material than other guards. There is a minimum opening for the grinding operation. In addition, these guards often enclose the spindle end, nut, outer flange, and side of the abrasive wheel. The guard may form part of an exhaust system that collects particles from the operation. It may have a work rest attached to it and have enough structural strength for that purpose. Because there are many kinds of grinding operations and grinding wheels, there are many variations and additional design features for each variation.

Devices

Point-of-operation devices provide protection when it is not possible to provide an adequate guard. Point-of-operation devices ensure that the machine cannot operate or create a hazard while an operator has fingers or hands in the point-of-operation. For example, it may be necessary to open a guard to insert or remove materials the machine must act on. That allows hands to reach the hazardous area of the machine through such openings.

There are many kinds of point-of-operation devices. They include gates or moveable barrier devices, presence sensing devices, pull-out devices, sweep devices, hold-out or restraint devices, two-hand controls, and hand-feed tools.

Automatic or Semiautomatic Feed and Ejection One means of preventing the need to place fingers and hands on the point-of-operation is the use of automatic or semiautomatic feed and ejection equipment. Automatic devices require no action by an operator. Semiautomatic devices require an operator to start a control. Operators feed and remove materials through openings in an enclosure guard (Figure 13-11). Some machines use mechanical actions, air pressure and gravity to feed and eject materials. The guard openings should meet the criteria in Table 13-1 and Figure 13-3. The means to accomplish this depends on the machine, its function, the material acted on, and other factors.

Gates or Moveable Barrier Devices These devices have panels or barriers that open to allow insertion and removal of materials. These devices must enclose the point-of-operation before the machine can start. When the gates or barriers open, they must stop the machine.

Presence-Sensing Devices Presence sensing devices detect whether the operator's fingers or hands are or could be in the point-of-operation. If they are, the machine will not operate or will stop quickly enough to prevent injury. Presence-sensing devices are not a suitable alternative for some machines. Each type of device has particular limitations. Guards should protect all areas not protected by presence-sensing devices.

The sensing device must be far enough from the danger point to assure that someone cannot reach into the point-of-operation faster than the time needed to stop the machine.

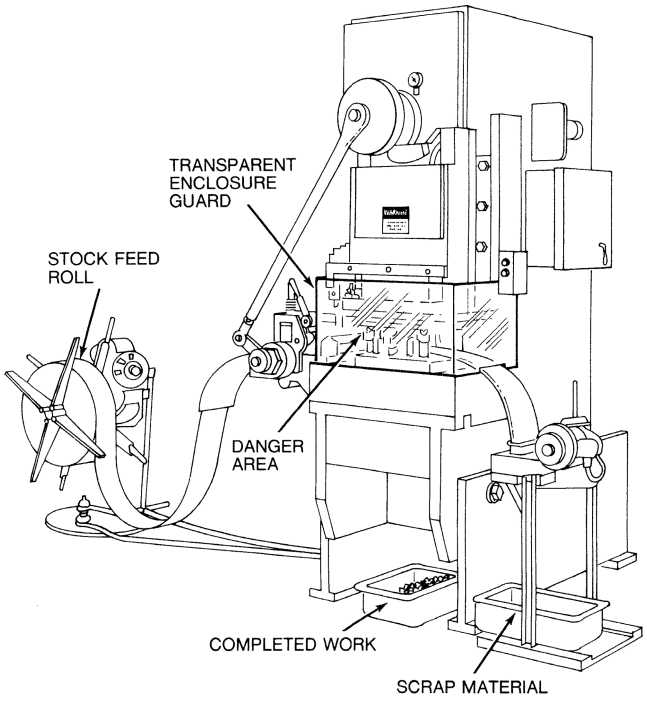


Figure 13-11. Example of a guard combined with automatic feed. (From OSHA 3067.)

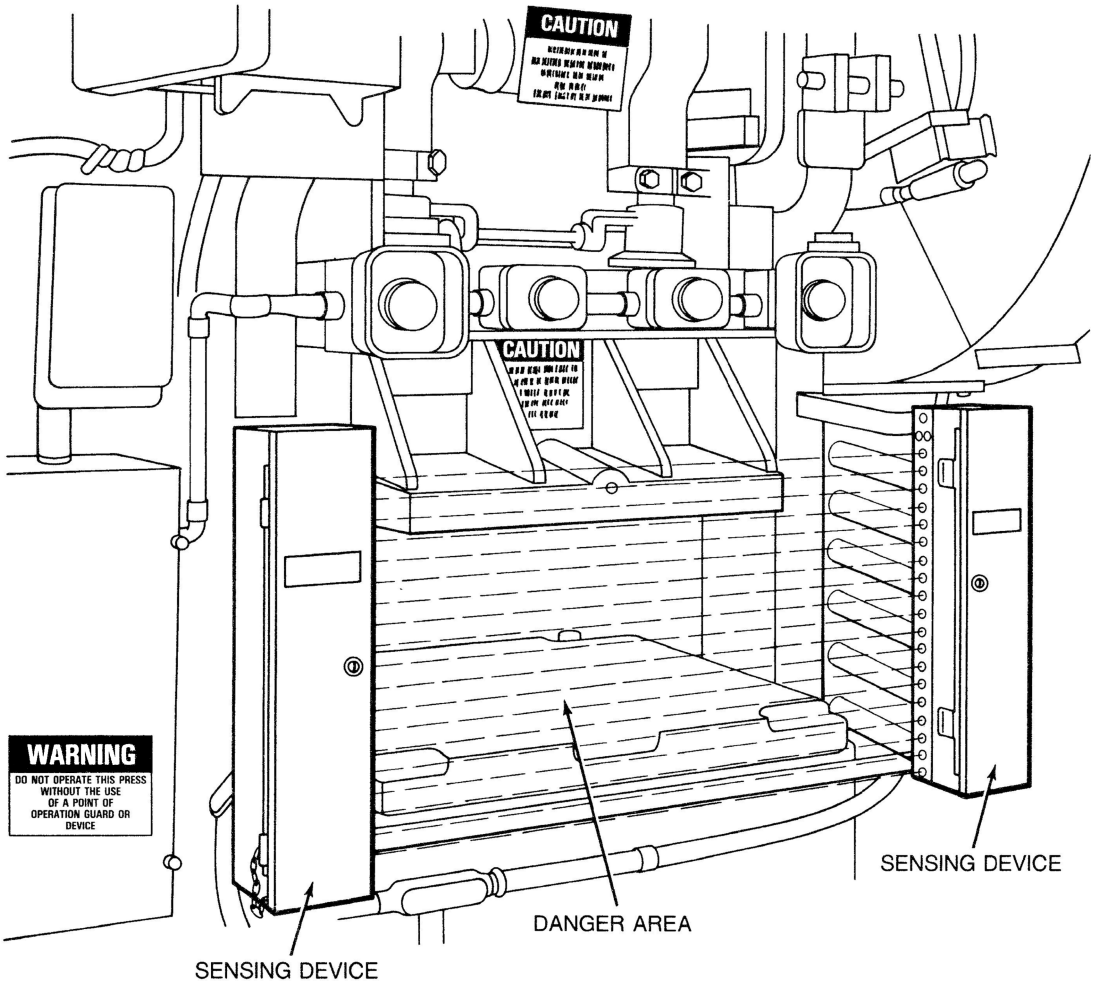


Figure 13-12. Example of a photoelectric presence sensing device on a machine. (From OSHA 3067.)

OSHA uses the following formula to establish the safe distance D between the sensing point and the point-of-operation

$$D = 63 \text{ in./s} \times T_s \qquad (13\text{-}1)$$

where

D is in inches from the point-of-operation
63 in./s is an assumed hand speed
T_s is the stopping time of the machine in seconds

One must check presence sensing devices from time to time to be sure they are working properly. Sometimes an indicator light combined with the control circuit notifies the user of a failure. Assuming a device is working properly when it is not could result in an injury.

Mats One kind of presence-sensing device is a mat that detects whether someone is standing on it. Position these mats in locations near a machine where someone could reach into the point-of-operation. When someone is on a mat, it can shut off a machine.

Photoelectric Beam Another type of presence-sensing device uses light beams and photoelectric sensors (Figure 13-12). An array of beams forms a horizontal, vertical, or combined pattern. If someone inserts something into the array and it interrupts one or more of the beams, the machine stops or will not operate. Because the array is not easily seen, one must depend on a display to know if it is functioning correctly.

Radio Frequency Field Another kind of device uses a radio frequency field. Electronic circuitry that creates the field detects the presence of a human body or body part. An antenna positioned around the point-of-operation creates the field. The antenna may be a wire or conduit. The sensitivity of the field is adjustable. Grounding characteristics for an operator may change with position and other factors, such as humidity and conductivity of shoes, and affect the reliability of some models.

Mechanical Some machines include a mechanical sensing device. For example, on a riveting machine, a ring

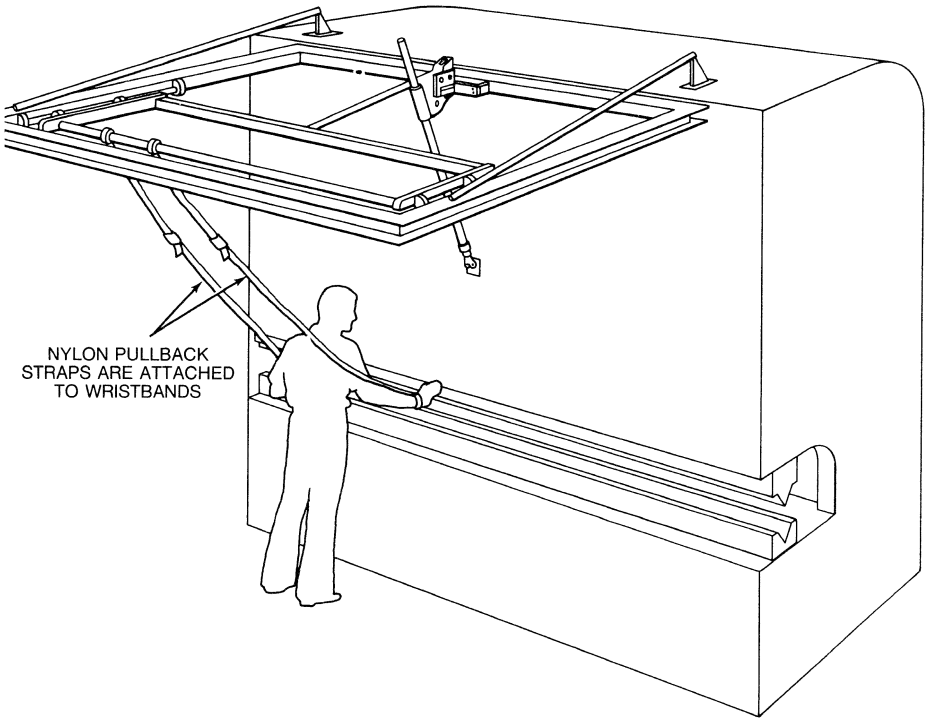


Figure 13-13. Example of a pull-out device. (From OSHA 3067.)

surrounding the point-of-operation moves down first. If a finger or hand obstructs the ring's full motion, the machine will not cycle the riveting action.

Pull-Out Devices Pull-out devices (Figure 13-13) are mechanisms that attach to an operator's hands and connect to the moving part of the machine, usually by a lightweight cable. This setup couples the motion of the machine with the operator's hands so the machine action will pull the hands out of the point-of-operation before they can get injured. To assure their effectiveness, these devices have a proper fit and adjustment for each worker. Someone must check the rigging before each use to assure that the device will be effective.

Hold-Out or Restraint Devices A hold-out device is a mechanism that connects the operator's hands to some point of restraint. When properly fitted and adjusted, hands and fingers cannot reach the point-of-operation.

Sweep Devices A sweep device is a mechanism connected to the point-of-operation action of a machine. The device sweeps an operator's hands or body away from the point-of-operation if present when the machine action begins. Some standards do not allow use of sweep devices. In some applications sweep devices can create a shear hazard between the sweep and some other machine component that can cause injury to an operator.

Two-Hand Controls A two-hand control device (Figure 13-14) is an electronic or pneumatic control assembly that requires an operator to place pressure on a control with each hand during all or most of the machine operation. The design prevents hands from being in the point-of-operation when they are on the controls. Designs must prevent operators from using one hand or arm or one hand and another part of the body to activate both controls. Some two-hand controls have a time delay limit between activation of two controls. This prevents someone from pressing one control, waiting or doing something else, and then pressing the second control with the hand removed from the first one.

Distance and Time The two-hand control must be far enough from the machine so one cannot reach into the point-of-operation after the machine starts in motion. Equation (13-1) would apply here as well.

Multiple Operators If there is more than one operator for a machine, each should have a separate set of controls. Each set of controls must link to all other sets. All operators must have their hands free of the point-of-operation before the machine can start its motion. In addition, when there are multiple operators, each should have an emergency shutoff within reach from their work position.

Hand-Feed Tools Hand-feed tools (Figure 13-15) are special tools that allow an operator to place materials into

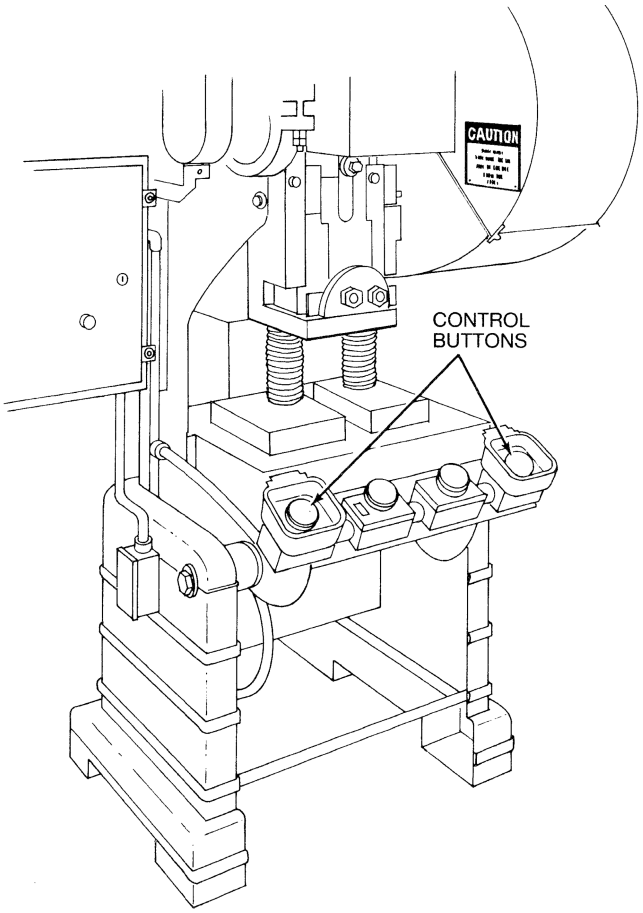


Figure 13-14. Example of a two-hand control device on a press. (From OSHA 3067.)

the point-of-operation or remove them without inserting hands or fingers. On some machines, such as table saws, jointers, and belt sanders, push blocks and push sticks have a similar use. They keep hands and fingers away from the point-of-operation.

Awareness Barriers An awareness barrier does not prevent access to the point-of-operation but it does alert people to a hazardous area or operation. It may work either of two ways. It may be a guard rail, gate or similar barrier that prevents easy entry or access to the hazardous area. A barrier may contact any part of the body of a person exposed to the point-of-operation to let them know that they are near or approaching a hazard. An awareness barrier should have a warning to explain the machine's hazards and the purpose of the barrier.

Awareness Signals These are audio or visual signals used with point-of-operation safeguards. The signals alert an operator or others that a hazard exists or is approaching. As long as an operator sees or hears the signals, there is an opportunity to take protective action.

Emergency Stop Controls An emergency stop control is an electrical, mechanical, pneumatic, or other control used to stop or de-energize a machine when an emergency occurs. An emergency may include someone getting caught in the machine or point-of-operation. An emergency control overrides all other controls and requires a separate control to restart the machine. Emergency stop controls should be at locations where an emergency can arise and where operators and others can reach them easily. Stop controls are red, clearly labeled, and require only momentary contact to activate them. They are usually larger than other machine controls, so they are easy to locate and operate. In a machine that requires an operator to use both hands for the operation, it may be difficult to reach for an emergency stop control when an emergency occurs. Providing a foot-operated emergency stop is a solution.

There may be a need for multiple emergency stop controls if a machine is large or if one emergency stop control is difficult to reach or get to by someone other than the operator. If there are multiple operators, each should have easy access to an emergency stop control. If there are multiple operator positions, there should be an emergency stop control within easy reach of each position. An emergency stop that is not within reach by a worker who gets caught is not of value to the operator. Some machines combine emergency stop controls with braking devices to stop the machine quickly or reverse the motion to make it safe.

Some machines use a pressure-sensitive body bar, safety trip rod or trip wire, cable, or cord. Requiring a worker to reach over a pressure-sensitive body bar to perform some function near a point-of-operation will allow any excessive leaning to trip the control and stop the machine. Pushing or pulling on a trip rod or trip wire will also stop machines in an emergency.

Other Machine Safeguards

Depending on the kind of machine, there may be a need for other safeguards.

Anti-Repeat Many machines operate one cycle at a time. An operator inserts a part into the machine and then activates the machine, which operates on that part and stops. Then the operator removes the completed part. The operator gets used to the rhythm of the machine. If, on occasion, the machine cycles more than once, the operator may have reached into the point-of-operation at the end of the first cycle and injury can occur. Where this situation might occur, the design for a machine action must incorporate an anti-repeat mechanism as a safeguard to prevent an inadvertent extra cycle.

Brakes Some machines, like certain presses, have elevated components that may fall due to gravity. Therefore,

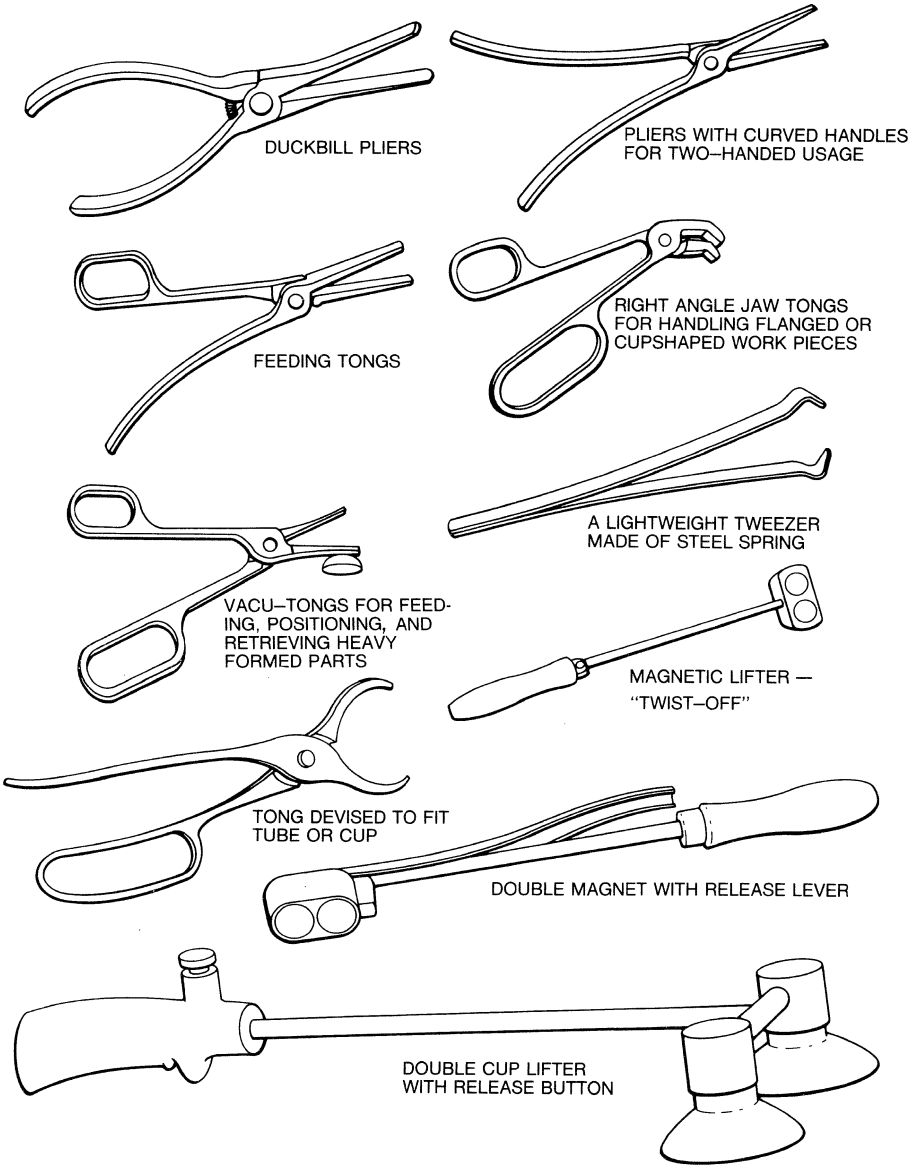


Figure 13-15. Examples of hand feed tools. (From OSHA 3067.)

they have a mechanical brake to keep the elevated components in position until a control cycles the machine. Some machines have brakes that can interrupt a machine at any point in its cycle.

Brake monitors determine whether a mechanical brake is performing correctly on each cycle. The monitor displays a position reading. If the brake does not stop the machine component at a desired position within some tolerance, the operator will know the brake needs maintenance.

Other machines, like rubber mills and calenders, use reversing current in the drive motor to stop the rolls when someone activates an emergency trip wire or switch. According to some standards, the rolls must stop within 1½% of the peripheral no-load surface speed of the roll.

Many circular saws and other rotary machine actions continue rotating for some time after they are shut off. Electronic motor brakes can stop the rotary motion within 1 to 2 s after the power is off.

Foot Controls Foot controls actuate some machines or a machine cycle. Something falling on them can inadvertently trip them. Someone can inadvertently steps on them. However, a guard over the control and recessing the control inside the guard will prevent most of these occurrences (Figure 13-16). There is a variety of designs for foot controls and foot control guards. Some have a pin that locks them when not in normal use to prevent inadvertent operation of the machine.

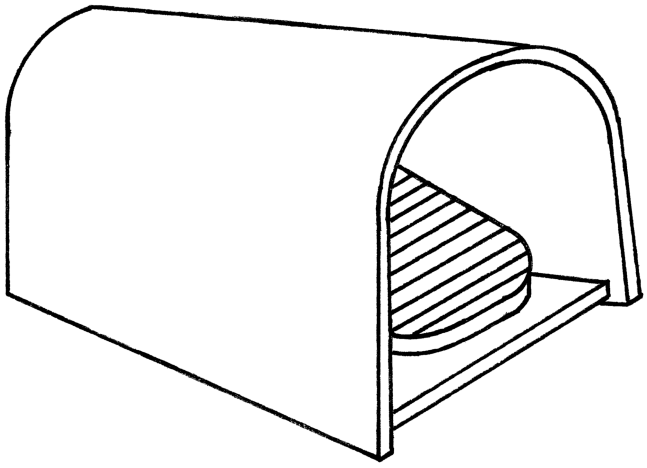


Figure 13-16. Example of a foot control guard covering the top and sides of a foot-activated switch.

When an operator keeps a foot on a foot control between cycles, it is possible to activate it at the wrong time. To help prevent inadvertent operation, foot controls should have a significant resistant force and require an amount of movement consistent with intentional actions. Human factors literature and other sources give criteria for minimum switch movement.

Jog Control During cleaning, maintenance or setup operations, it is often necessary to move machine components to certain positions. Controls for normal operations make this difficult and dangerous because they run at operational speed. One means for accomplishing small movements is with a jogging control. Jog controls allow an operator to turn a machine on and off quickly producing a short machine motion. When pressed or pushed, a jog control runs the machine. When released, the control stops the machine without any additional action on the part of the user. Some jog controls also operate the machine at speeds well below normal operating speeds, making the positioning tasks easier.

Low Energy Operation and Inch Controls A low energy mode and low speed (inching) controls can reduce the hazards of machine operation during setup, maintenance, or cleaning. The machine may have a mode control switch that has a normal speed or energy position and a slow speed or reduced energy position. In some cases, manual power, such as a hand wheel or crank, may provide the low energy. Because the machine runs significantly slower compared to its normal operation, an operator has a much better chance to react to dangers and avoid injury. It is preferable to have fully stopped and de-energized machines unless there is a clear need for low speed or inching for setup, maintenance or cleaning.

Mode Selection Some machines operate in different modes. Modes may include continuous operation, single cycle, low energy, or de-energized. A keyed control selects the desired mode. A supervisor or operator places a key into the control and turns it to the desired mode. The operator or supervisor removes the key to lock the selected mode. A key procedure helps ensure that someone does not change the mode without appropriate safeguards in place. A mode selection switch does not replace lockout and tagout procedures. Standard operating procedures may require lockout and tagout procedures in combination with keyed mode control procedures.

Run Controls Run controls turn on a machine and its action. If someone inadvertently turns on the run control or something presses or falls against it, hazardous conditions may result. Putting guards on or recessing run controls prevents accidental starting of a machine. Chapter 33 discusses various methods for guarding switches and run controls from inadvertent activation.

Blocks and Stops During maintenance and setup activities, the ram on a press could fall and cause injury. It is good practice to insert a die block or safety block to prop the press open (Figure 13-17). Some presses have an attached rack to store the die block for normal operations. The rack has a switch or interlock that de-energizes the machine when the die block is not in the rack.

Anti-Kickback Devices Circular table saws and similar machines have the capability of throwing or "kicking back" stock that binds or catches on the blade. A 2 in. × 2 in. piece of lumber thrown by a large saw has enough energy to penetrate an operator's chest. An anti-kickback dog is a device that allows material to move freely into the saw blade, but pinches the material against the saw table if pulled or pushed backward. A similar device, called anti-kickback fingers, protects radial saw operators during ripping operations.

Warnings

Machines need one or more warnings to communicate hazards that may be present. Warnings also explain protections needed. For example, if there are guards for a machine, the warnings should include a notice to keep guards in place and not operate the machine without them. When there are guard devices, the warnings should state the hazards or dangers, any limitation the device may have and protective actions the operator must take. See also Table 7-1.

Robots

Industrial robots have become quite common. The development of manufacturing, walking, and flying robots is

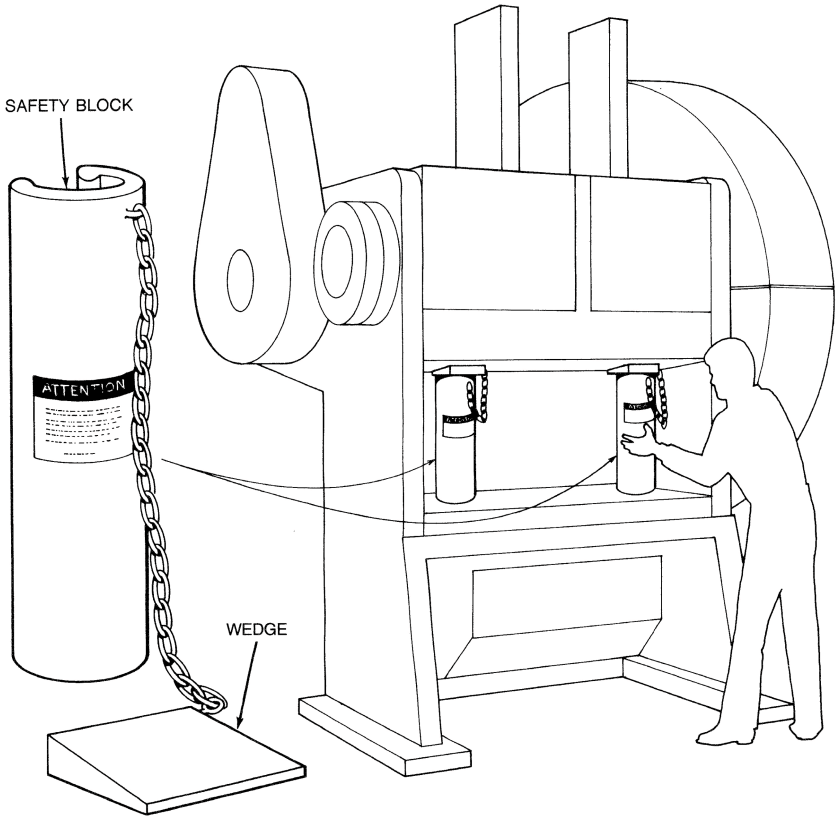


Figure 13-17. Example of a safety block for presses. (From OSHA 3067.)

exponential[2]. A robot is "taught" or programmed to perform certain movements and functions. Robots have many of the same hazards that machines do. Some robots have multiple functions and multiple hazards. In addition, their movements are less predictable than simpler machines, since many robots have multiple operations and operators may not know which action might come next.

The volume of space enclosing the maximum designed reach of the robot or objects it manipulates is the work envelope. One or more safeguard devices protect the work envelope for normal operations. These safeguard devices include presence sensing devices, barriers, interlocked barriers, perimeter guards, awareness barriers, or awareness signals. If an operator must enter the work envelope to maintain or train the robot, there must be additional safeguards. Servicing of robots may require lockout and tagout procedures, reduced operating speed (10 in./s or less), blocks or stops, emergency shutoff controls, keeping a second person at the robot control panel, and other safeguards.

Pendant Control A pendant control may also help safeguard workers involved with robots. A pendant control is a moveable control rather than one at a fixed location. A pendant control allows an operator to operate a machine from multiple locations. Pendant controls help workers operate a robot from within the work envelope. The pendant control for a robot must have certain features. It must be a single point of control. No other controls can operate the robot when it is in the pendant control mode. The robot motions should operate only at slow speeds. Like jog and inch control, the robot motions must stop when an operator releases buttons or other controls on the pendant. The pendant control should not place the robot in automatic mode. The pendant control must have an emergency stop switch.

Safeguarding Procedures

Guards and guard devices may not provide enough protection for all the operations and activities involved in the use, maintenance, cleaning and repair of machines and tools. Several safeguarding procedures will help prevent accidents from occurring. Remember, procedures do not remove hazards.

Training An operator of a machine must learn to perform all the tasks associated with the machine. Operators must learn which hazards a machine has and which safeguards protect users from each hazard. Operators must learn the

location of every control and what it does. Especially important are emergency stop controls. They should know how to adjust a machine and perform setup, maintenance, repair, and cleaning tasks in a safe manner.

It is not enough to learn how to run a machine. Operators must learn to recognize and manage contingencies. They should learn what can go wrong, what hazards such situations present and how to deal safely with them when they do occur.

Enforcement Employers must ensure that workers follow correct and safe operating procedures. Employers and workers must be sure that all guards and guard devices are in place and working properly. Feedback from workers can provide ideas for making equipment and related operations safer.

Inspections Machines should have regularly scheduled inspections to detect potential problems early. Inspections should include regular checks and tests of guards and guard devices. Work orders should correct hazardous conditions or inadequate safeguards before returning a machine to use.

Clothing and Jewelry Loose clothing, jewelry (particularly rings), and long hair can catch in many machine motions, pull parts of a body into a machine and cause injury. During machine use it is good practice not to wear jewelry or loose clothing, and to keep long hair covered.

Some machines and operations create hazardous environments for operators. They may need protective clothing to reduce dangers. Analysis will identify environmental hazards of each machine. Then, one can select and use appropriate personal protective clothing or equipment.

Lockout and Tagout Procedures During setup, maintenance, or cleaning, workers must lock out and tag out a machine before beginning service. This will prevent anyone from activating it inadvertently or while someone else expects it to be de-energized.

Zero Mechanical State Zero mechanical state (ZMS) recognizes that locking out the main power sources of a machine or system may not remove all sources of energy. Pneumatic, hydraulic, or other fluid lines or components may still have pressure and need venting or isolation to make them safe. Someone may need to close valves from other energy sources. Springs may have stored energy and require blocks or other means to secure them. Gravity may cause suspended or loose components to fall or cause movement in the machine. There must be restraints for such items. The ZMS concept recognizes that detailed procedures will help ensure that a machine or system is safe for maintenance, setup, or cleaning operations.

13-5 CONTROLS FOR HAND TOOL HAZARDS

Two main groups of controls for hand tool hazards are safe practices and safeguards.

Safe Practices

This section identifies several safe practices that apply to many hand tools. In addition, there are individual practices that apply to particular tools. References on hand tools and manufacturers' publications give particular safe practices.

Select the Right Tool for the Job Every hand tool has a purpose and includes certain features for its purpose. Proper selection will prevent misuse.

All too often, people try to make do with an available tool, rather than get the correct one. One example of a wrong use is opening a paint can with a screwdriver, which could slip from the lid and puncture the hand. There are inexpensive tools for opening paint cans. They have a lip that goes under the rim of the lid to lift it without much force and have little chance of slipping.

Other examples of wrong uses are using the wrong-sized screwdriver for a fastener or using a screwdriver for a chisel. Also, striking hard objects or hardened tools with a carpenter's hammer that has a hardened face can cause fragments to break loose. Using a pliers for a wrench is another common tool misuse.

Know the Hazards of the Tool Closely associated with the function of each tool are particular capabilities, limitations, and hazards. For example, a carpenter's hammer, like certain other kinds of hammers, has a hardened face. If it strikes another hardened tool or some hard object, the face is likely to spall, causing fragments that can fly into one's eye. Sledgehammers have a softer face making them more appropriate for such tasks. The tip of a screwdriver has hardened steel also. When someone uses it for chiseling or prying, it can fragment easily. The struck end of a chisel is intentionally soft so that it will not fragment easily. *An ax has a long handle to reach wood objects farther away whereas a hatchet has a short handle for short swings and nearby wood objects*. Adjustable and open-end wrenches do not fit nuts as well as box-end and socket wrenches. Therefore, because they may slip, such wrenches are not suitable to loosen frozen nuts or to perform final tightening.

Use Tools Correctly Socket wrenches have certain torque limits. Using handle extensions or adapters for smaller wrench sizes can cause sockets or wrenches to break. Sockets for hand wrenches are not strong enough for power or impact wrenches. Poor footing and excessive pulling on a wrench may cause one to slip and fall. Wearing eye protection when

using striking tools will prevent eye injuries. Using woven metal gloves for cutting operations with knives will prevent hand injuries.

Maintain Tools Inspect tools regularly to be sure that they are in good condition. Repair or discard broken, worn, or damaged tools. Broken handles on hammers, sledges, axes, and hatchets may cause the head to fly off and strike someone. Sprung or damaged jaws on wrenches can slip. Worn screwdriver tips can slip from the head of a screw and cause injury. Sharpen cutting edges to make cutting tools easier to use. Grind the mushroomed heads of impact tools, like chisels or drift pins, to prevent fragments from causing injury.

Store Tools Properly When tools lie around, especially sharp tools, someone may bump into them and get injured. Tools left in walk areas can create tripping hazards. Pointed tools left in pockets can cause injury if a person falls on them. Tool belts, boxes, chests, and cabinets can help keep tools in order and safe when not in use. Store sharp tools in protective sheaths when not in use.

Tool Safeguards

There are several safety features found on tools that can help prevent injuries. Certain kinds of tools have particular safety features.

Tool Guards When striking cold chisels, star drills, and other tools, there is the danger of missing the tool head and striking the hand that holds the tool. There are guards that can protect hands. A round pad of foam or more solid material with a small hole can slip over the tool and on top of the hand. If one misses the tool, the guard will absorb some of the shock and reduce the likelihood of injury.

Some knives have blade guards that keep the user's hand from sliding down the handle onto the blade (Figure 13-18). Such guards are particularly useful when hands are wet or greasy, such as in meat cutting.

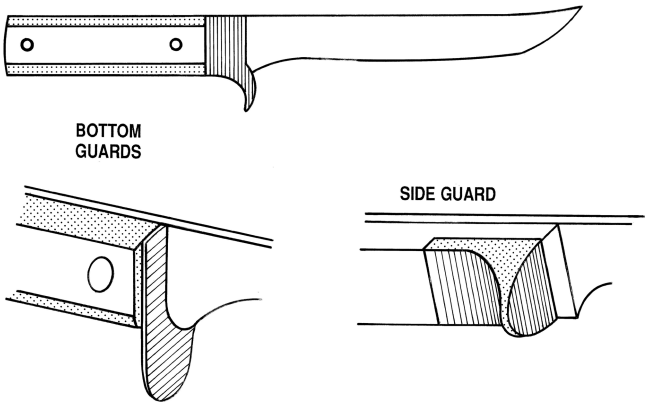


Figure 13-18. Examples of blade guards on knives.

Handle Design Handles on tools come in a variety of shapes (Figure 13-19). Not only do lengths vary, but so do cross-sections, which normally vary over the length. Some tools (hatchets, for example) have enlarged ends to minimize the chances of the handle slipping from the hands. Long handles on tools like axes and sledgehammers keep the tool at some distance from the user. They allow for full swings and keep the tool from striking the user's legs and feet. Some tools have short handles for work close to the body. They require partial swings.

The rationale for some handle characteristics is not clear. Recently, however, handle characteristics have received some attention. In the 1950s, Damon and others at Western Electric in Kansas City developed bent handles for needle-nose pliers used in electronics assembly. In the 1970s, without knowledge of previous work, Bennett patented handles for tools and sporting goods. His patent has a bend of $19 \pm 5°$ and a particular aspect ratio for the handle cross-section. He noted that when one curls the fingers to grasp something, the opening formed by the fingers is not round. Rather, it is oval. He also noted that when one grips some tools, the user's wrist bends to its limit. He chose to bend the handle instead. Figure 13-19 compares a straight and bent handle and associated wrist frexion.

Handle designs affect the biomechanics of arm and wrist motion. Carpal tunnel syndrome and certain related hand and elbow disabilities may gain relief by adjustments in the shape or length of handles. For many tools, bending the handles reduces bending of wrists. Some handle designs help transfer forces from the wrist and elbow to more powerful shoulder and back muscles. Bent handles for such tools as pliers, hand-held cutting tools, hammers, and lopping shears may reduce repeated trauma disorders and enhance use.

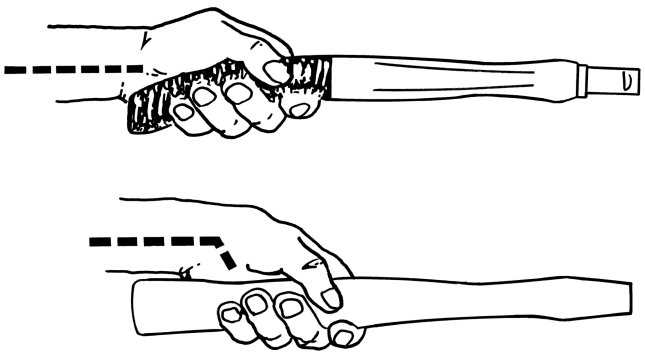


Figure 13-19. Examples of a bent handle compared to a straight handle. The bent handle allows the user to hold the wrist straight, while the straight handle requires more bending of the wrist.

Muscles generate their greatest force when they are about midway through their range of motion. Thus, fingers generate the strongest grip when they are half-flexed. The flexion of the wrist joint also affects the ability of the fingers to grip something. For example, when the wrist is fully flexed, it is difficult to grasp something tightly with the fingers.

During use, some tools create pressure in the hand. Examples are pushing on the end of a broom handle, gripping something with a pliers or cutter and pushing on a paint scraper or putty knife. Special handle shapes can distribute the load against the hand over a greater area. This reduces the likelihood of tissue compression disorders.

High-friction plastics can increase the coefficient of friction between the hand and a tool it holds. Many tools have such plastic grips. There is a potential disadvantage for this material. If there is a tendency for the handle to slip against the skin, one can develop abrasion injuries.

This high-friction plastic material also comes in a moldable form. This permits custom shaping of handles for individual users. Such handles conform to the natural shape of a user's hand and reduce the forces needed for a good grip.

13-6 PORTABLE POWER TOOL CONTROLS

Training

Users of portable power tools need training to use them safely and properly. Training should include how to operate the tools. Users need to understand the hazards of each tool, its action, and power supply. They need to know about built-in protections. They need to know how to protect themselves from hazards during use. They need to know how to maintain and store the tools.

Proper Use and Condition

Like other tools, portable power tools have designs for particular tasks. If used for other tasks, they may create additional hazards.

Tools must be in good condition to perform well and produce quality work. For example, blades must be sharp, because when they are dull, a user must apply extra force. Guards or other protective devices must be in place and operational.

Start Switch Lockout

Some power tools have a lockout for the start switch. The idea is to prevent inadvertent operation. A tool cannot operate until a keyed switch selects the operating mode.

Some power tools have an extra button to depress before the power switch will operate. For example, someone could accidentally turn on a portable power saw that has no lockout button on the start switch. When picking up the saw by the handle, a finger could inadvertently activate the power switch. On some power-actuated tools, a user must release a safety switch before the tool will operate.

Interlocks

Some tools have interlocks that protect the operator or others. For example, a riding mower has a switch under the operator's seat that shuts off the blades or engine when the operator stands up or gets off the mower. This protects the operator from being run over or getting a foot under the mower deck. Riding mowers have an interlock switch that stops the blades or engine when the operator selects reverse gear. This prevents the mower from backing over someone with the blades engaged.

Powder-actuated tools have a guard over the driver end. The user presses the guard against the surface that will receive a fastener from the tool. The guard has an interlock linked to the activating switch or trigger. If the operator does not press the guard against a surface, the trigger cannot activate the tools and drive a fastener.

"Dead Man" Switch

Many power tools have switches that shut off power to the tool when the operator releases the switch. Depressing the switch turns the tool on. Releasing the switch turns it off. Portable drills, saws, hedge trimmers, grinders and other power tools have such controls. The operator must depress the switch continuously during use. If the operator leaves the operator position or lets go of the control, the tool stops. There is little chance of injury to the operator.

For some tools, like mowers, standards require that the action of the tool stop within a certain time. This prevents the user from moving to a position of danger while the dangerous part of the machine is still in motion or coasting to a stop. Mowers have shut-off switches under seats that turn off power when the operator leaves the seat.

Vibration

Continuous use of vibrating tools can result in temporary or permanent disorders.[3] A primary goal is to design the tool to minimize vibration. For some tools with vibration, a protection limits the duration of use. In some cases, tools have isolating material to prevent the vibration within the machine from reaching the operator's handles and controls. It may be possible to reduce its amplitude. One option is incorporating isolation pads within the machine. Providing isolation on handles may reduce the vibration reaching an operator.

Riding on machines and vehicles can create whole body vibrations and injuries. Designs for suspensions and seating may reduce the potential for such injuries.[4]

Guarding Tool Action

Many portable power tools have the same dangers as fixed power tools. When a tool has any of the five kinds of dangerous machine actions (see Section 13-2), they will need safeguards. The aim is to provide guards where possible. For some equipment, guarding is difficult. For example, one cannot cover the cutting action of a chain saw. Other features, such as blade brakes and anti-kickback designs, reduce the potential for contact with the cutting chain.

Personal Protective Equipment

The dangers of each kind of hand and power tool will dictate the need for and type of personal protective equipment. Chapter 28 provides more details about personal protective equipment.

Certain power tools may require specific personal protective equipment. For example, there are coveralls designed for use with chain saws. The outer fabric is tough. The cutting chain does not easily cut through it. This extra layer of tough material prevents the chain from contacting the user's skin.

Safeguarding Energy Sources

There are hazards associated with the energy sources for powered tools. One must consider these hazards and provide suitable hazard controls. For example, electrically powered equipment should have the safeguards discussed for electricity in Chapter 12. Chapters 16 and 17 address controls for hazards of gasoline or other flammable fuels used in mowers, trimmers, and other tools. Chapter 19 covers controls for air and fluids under pressure that power some tools.

13-7 STANDARDS, REGULATIONS, AND GUIDES

There are many sources of information about safe machine and tool operations and use. The array of sources can be helpful or confusing. Not all sources may offer the same rules or guidance for safe use of machines and tools. In addition, there are continual updates that reflect changes in machines and tools and changes in safety considerations.

Manufacturers typically provide a manual with their machines. The manuals cover hazard identification, safeguards, proper operation and maintenance. Good manuals use imperative writing style that tells users what to do. Manuals that simply describe the features of a machine are not as helpful and effective. Those who buy machines should keep the manuals so the information is available for reference and training. Some major distributors and sellers of machines and tools also offer safety information and guides.

Manufacturers associations produce training and instructional information for the machines and tools offered by their members. Some offer written materials and visual materials in a variety of formats.[5]

There are organizations that produce standards and guidance for various kinds of machines and tools, and their operations. These are professional societies and standards organizations in various countries. For example, a long-standing machine safety standard produced by the American National Standards Institute (ANSI) is the B-11 series. What was initially a single standard has grown to more than 40 standards in the B-11 and related groups.[6] Some unions also offer information on safety of machines.

Government organizations also produce regulations, standards and guidance for a variety of machines and tools. Each country may have its own government standards and regulations. The U.S. Occupational Safety and Health Administration (OSHA) standards for machine and tool safety appear in 1910 Subpart O - Machinery and Machine Guarding[7] and 1910 Subpart P - Hand and Portable Powered Tools and Other Hand-Held Equipment.[8] Oregon OSHA published a guide to point-of-operation machine guarding.[9] Examples of machine safety guidance document are those offered by the Government of Western Australia.[10]

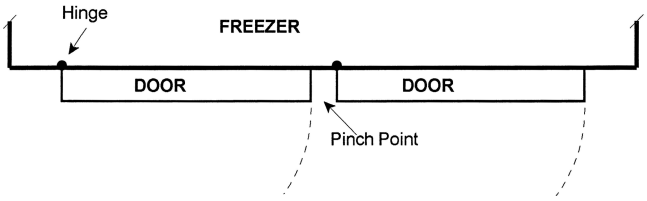
In addition to specific information on machine and tools safety, there are other sources of guidance, standards and regulations for power, use environments, and the materials processed. Table 13-2 provides an incomplete list of sources for machine and tool safety information, standards, and regulations.

TABLE 13-2 Select Sources of Safety Information, Standards and Regulations for Machines and Tools

Manufacturer Associations
Hand Tool Institute
Power Tool Institute
National Tooling and Machining Association
Association of Manufacturing Technologies
National Electrical Manufacturers Association
Semiconductor Industry Association
National Association of Manufacturers
Robotic Industries Association
Canadian Tooling and Machining Association
Unions
International Association of Machinists and Aerospace Workers
United Auto Workers
Standards Organizations
Society of Manufacturing Engineers
American Society of Safety Engineers
American Society of Mechanical Engineers
American National Standards Institute
International Standardization Organization
Government Regulation Sources
Occupational Safety and Health Administration (U.S.)
European Commission (EU)

EXERCISES

1. A point-of-operation guard will be installed on a machine with a feed table. An operator will feed material into the machine. The material will be 1 1/8 in. thick and require a 1/8 in. clearance in an opening in the guard. How far must the guard be from the danger line?
2. Two in-running rolls (with no feed table) compress parts fed into them. The rolls are each 4 in. in diameter. There is a 1/8 in. gap between them and the material is 5/8 in. thick before compression in the rolls. A guard will protect the pinch point. The opening for the material will have a 1/8 in. clearance. Determine:
   (a) where the danger line is located relative to the center line between the rolls
   (b) the location for the guard relative to the danger line
3. A calender machine used to add materials when preparing rubber has 18 in. diameter rolls. The rolls rotate at 60 rev/min.
   (a) What is the surface speed for the rolls?
   (b) If the rolls must be stopped in an emergency, what surface distance must not be exceeded, according to OSHA standard 29 CFR 1910.216(f)(3)(i)?
4. A machine will have a presence-sensing device and an interlocking barrier gate. How far should you locate a two-hand trip control from the point of operation?
5. The doors on a food storage refrigerator or freezer in a supermarket are close together. Because of their design when opened, the hinge side can create a pinch point for someone other than the door operator, such as a child accompanying a parent. The design below is a cross-sectional view of two adjacent doors. What alternate designs for the door structure will reduce or eliminate the pinch point between the doors?



Exercise 13-5. Top view of freezer doors in Exercise 5.

6. Visit a local manufacturing company that uses robots in production.
   (a) Find out what protections the company has in place for normal operations.
   (b) Find out what protections they have in place for maintenance, cleaning, and repair.
   (c) Find out what standards the company follows for robot safety.

REVIEW QUESTIONS

1. What are four kinds of hazards of tools and machines?
2. What additional hazards do power sources (such as gasoline, electricity, compressed air, or hydraulic fluid) add to tools and machines beside the hazard of the tool and machine actions?
3. What kinds of injuries can tools and machines inflict?
4. What are cumulative trauma or repeated motion disorders?
5. Describe the symptoms for each of the following:
   (a) trigger finger
   (b) carpal tunnel syndrome
   (c) Raynaud's syndrome
   (d) Dequervain's disease
   (e) bursitis
   (f) perimyotendinitis
   (g) tenosynovitis
   (h) epicondylitis
   (i) ganglion cysts
   (j) rotator cuff
   (k) thorasic outlet syndrome
6. When was the first patent issued for a machine interlock?
7. About when were standards for machine guarding formalized?
8. What functions can machine guards serve?
9. What safeguards are necessary for maintenance, cleaning, and setup of machines?
10. If openings are required in guards, how is protection provided?
11. What criteria are important in guard construction?
12. What are the five kinds of machine motions and the hazards of each?
13. Explain the following safeguards:
    (a) guards
    (b) devices
    (c) distance
    (d) location
14. What safeguards may protect power transmission equipment?
15. Describe each of the following point-of-operation guards:
    (a) enclosure guard
    (b) interlocked guard
    (c) adjustable guard
    (d) special guard

16. Describe the following point-of-operation devices:
- **(a)** automatic or semiautomatic feed and ejection devices
- **(b)** gates or moveable barrier devices
- **(c)** presence-sensing devices
- **(d)** pull-out devices
- **(e)** hold-out or restraint devices
- **(f)** sweep devices
- **(g)** two-hand controls
- **(h)** awareness barriers
- **(i)** awareness signals
- **(j)** emergency stop controls, including trip rod, trip wire, and body bar

17. Describe the following machine safeguards:
- **(a)** anti-repeat mechanism
- **(b)** brake
- **(c)** brake monitor
- **(d)** foot controls
- **(e)** jog control
- **(f)** low energy control
- **(g)** mode selection
- **(h)** run control
- **(i)** block or stop
- **(j)** anti-kickback device

18. What roles do warnings have in safeguarding machines?

19. What safeguards are used for robots?

20. What safeguarding procedures are important for machines?

21. Describe the following:
- **(a)** lockout and tagout procedure
- **(b)** zero mechanical state
- **(c)** key procedure

22. What safeguards are important for hand tools?

23. What safeguards are important for portable power tools?

24. Describe the following power tool safeguards:
- **(a)** start switch lockout
- **(b)** interlocks
- **(c)** dead-man switch

NOTES

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2 Neil Fine, Editor, *Rise of the Robots*, Time Home Entertainment, Inc., New York, 2013.

3 www.ccohs.ca/oshanswers/phys_agents/vibration/vibration_effects.html

4 www.hse.gov.uk/VIBRATION/wbv/index.htm

5 www.powertoolinstitute.com/pti_pages/safety_videos.asp

6 webstore.ansi.org/RecordDetail.aspx?sku=ANSI+B11.+Machine+Tools+Safety+Package; www.rockfordsystems.com/list-of-ansi-b11-standards.html

7 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10131

8 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10132

9 www.orosha.org/pdf/pubs/2980.pdf

10 www.commerce.wa.gov.au/sites/default/files/atoms/files/vwa_machine_safety_l.pdf; www.commerce.wa.gov.au/sites/default/files/atoms/files/safeguarding_of_machinery_and_plant.pdf

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CHAPTER 14

TRANSPORTATION

14-1 TRANSPORTATION ACCIDENTS

Most transportation-related accidents, injuries, and deaths involve motor vehicles. There are also accidents and incidents for other forms of transportation. The cases involve issues with vehicles and transportation equipment, the infrastructure, materials transported, the operators, people who maintain the systems, the management systems, government policies, and the public. This chapter touches on only a portion of these issues.

The Problem

Motor vehicles illustrate the importance of safety in transportation. According to the World Health Organization (WHO),[1] each year about 1.2 million people die on roads around the world. That amounts to about 3,400 each day.

The National Highway Traffic Safety Administration reports[2] in 2012 there were nearly 10 million vehicles involved in police-reported traffic crashes. Ninety-six percent of the vehicles were passenger vehicles (cars, light trucks, SUVs, and vans). About 21,000 occupants of passenger vehicles die each year in the United States and more than 2 million receive injuries.

In the National Safety Council estimates for 2012 in the United States,[3] there were about 36,000 motor vehicle deaths, 3.9 million medically consulted injuries, and an economic cost of about $276 billion.

Other Vehicle Accident Factors

In addition, studies have revealed several other facts about motor vehicle accidents, injuries, and deaths. The Bureau of Labor Statistics reported that in 2013 there were 4,628 work-related fatalities.[4] Of those, 1,740 (38%) were transportation-related cases. Of the transportation fatalities, 57% were roadway incidents involving motorized land vehicles, while the remainder involved off-highway, farm, and other kinds of vehicles. As a result, work-related transportation accidents are the leading cause of workplace injuries and deaths. The rate varies by type of work. For examples, police departments have a higher death rate from vehicle accidents than from gun shots. Sales and delivery workers have a higher incidence of vehicle injuries and death than office and manufacturing workers.

Note sources and other sources provide additional insights into transportation accidents. The highway accident rate is highest during late night hours, 10:00 p.m. to 4:00 a.m. Certain nights, such as Friday and Saturday nights, have higher rates than other nights. Death rates are much higher for cars than for pickup trucks, SUVs, and vans. While 86% of all vehicle occupants use seatbelts, 65% of rural pickup truck occupants killed were unrestrained.

Young adults aged 17–30 have the highest vehicle-related death rates. For those over 65, the vehicle-related death rate increases with age. Death rates are higher for males than for females, even when adjusted for the miles traveled.

About 50% of accidents involve frontal crashes. About 2% are rear-end collisions. Side crashes have a higher death rate than other crashes. Of the approximately 50,000 motor vehicle accidents in a year, about 8,000 involved rollover of the vehicle and more than 5,000 involved impact with trees and utility poles. In 2012, 79% of vehicle occupants who totally ejected in a crash died.

One of the leading causes of vehicle deaths is the blood alcohol concentration (BAC) of drivers. For the last decade, about one-fourth of the drivers in fatal crashes had BAC levels above the legal limit of 0.08 g/dL. There are measurable reductions in driver skills at BAC levels of 0.05.

With the widespread use of cell phones, smart phones, and text messaging, there is a lot of attention on distracted driving. There are many kinds of distractions for drivers. Included are texting, use of mobile phones, eating, drinking, talking to passengers, grooming, reading, use of navigation devices, watching videos, and adjusting radios, CD players, and other music devices. The distractions can be organized into three categories:

- manual: taking hands of the steering wheel;
- visual: taking eyes off the road; and
- cognitive: taking the mind off driving.

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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Driving for long periods leads to higher accident rates. Truck drivers who drove for 10 hrs had nearly twice the risk of being in a crash compared with drivers on the road for less than 2 hrs.

Passenger restraints and airbags contribute to lowering injury and death rates in vehicles accidents. Failure to have or use restraints increases occupant risks.

Vehicle size is an important factor in vehicle injuries and deaths. The average rates for drivers of small cars involved in crashes is over twice that for large cars. As noted, in general, occupants of cars do not fare as well as occupants of pickup trucks, vans, and SUVs.

Vehicle Crash Event Sequence

Vehicle crashes are dynamic and quite complicated. There are many factors that contribute to the actual crash sequence, depending on vehicle speed, design, and motion. However, a simplified discussion will explain some of the basic phenomena of vehicle crashes and impacts.

Frontal Impact When a vehicle runs into a fixed object or another vehicle in a frontal collision, there is a sequence of events that takes place within a fraction of a second. The amount of force at any point behind the point of impact goes down with distance depending on the amount of energy absorbed in the crash.

At very low speeds, the front structure absorbs some of the energy of impact. Older cars with bumpers had to meet one the NHTSA Federal Motor Vehicle Safety Standards (FMVSS; see Table 14-1) for bumpers. The standards had required vehicles to absorb low speed crashes at 5 mph and later at 2.5 mph. Now most vehicles have no bumpers because the front and rear structures are part of larger body parts. Vehicle designs today allow several front end structures to crush and absorb energy. Figure 14-1 illustrates this concept by plotting G load (the ratio of impact deceleration to the pull of gravity). At some distance from the point of frontal impact, there is little deformation of the vehicle structure. From that point rearward, the deceleration rate is almost constant over the rest of the vehicle length.

The aim of structural crushing is to reduce the energy of a crash that transfers to the interior. When a vehicle strikes another object or barrier, it stops quickly. Objects within or occupants continue to move at the original vehicle speed until they impact on something to slow them down. This is the "second crash," discussed below. Passengers restrained to the vehicle structure or its components will stop with the uncrushed part of the vehicle. Frontal air bags help prevent occupants from striking the interior in front of them.

Rear-End Collision[5] In a rear-end collision, one vehicle strikes another vehicle in front of it. The front vehicle is usually at rest or may be moving at some speed less than the striking vehicle. At slow speeds, the bumpers or structures will absorb much of the energy. At higher speeds the structure of the two vehicles will crush and absorb more energy. The front vehicle will accelerate forward unless restrained some way or is braking.

Within a few hundredths of a second after impact, the vehicle occupants in the forward vehicle will proceed through a series of movements, called whiplash. Whiplash can occur even at low impact speeds. First, the occupant's body will press into the seat back. The spine will straighten. The seat cushioning and structure will absorb much of the energy related to the rearward acceleration of the occupants. The seat back will flex rearward. The amount depends on the structure of the seat. The head rotates rearward. A headrest will limit head rotation. In part, that depends on the distance between the head and the headrest. In some cases, the head can also extend from the spine, a translation motion. The translation motion is greater if the seat back rotates a significant amount. Depending on the speed at impact, the amount of seat rotation, and effectiveness of passenger restraints, the body may slide backward up the slope of the seat. In some cases the head can strike the rear structure of the passenger compartment.

Rollover If there is enough lateral impact and movement, a vehicle may roll over. If tires slide and there is a change in resistance or they contact another object, a rollover can result. The vehicle structure may crush during the rollover, causing reduction of the occupant space. Because occupants may be thrown around, use of restraints will lessen the chance for injury. Some vehicles incorporate side impact structural elements to minimize reduction of occupant space. An increasing number of models include side impact air bags to cushion impacts on occupants and help restrain them from rollover injury.

The Second Crash

When a vehicle crashes, the occupants continue in motion until they impact on the interior of the passenger compartment. The term "second crash" refers to this crash of occupants against the interior surfaces of the vehicle following vehicle impact. Very often the second crash is the primary source of passenger injuries, not the vehicle crash itself.

Vehicles designed to absorb energy and reduce the transfer of forces to the occupants will reduce the second crash. Passenger restraints and air bags reduce the likelihood of the second impact. Well-anchored seats help minimize the second crash. A seat that comes loose from its anchors can add mass behind the passenger in a frontal crash. Unrestrained seat backs that separate from the lower portion of a seat add to the load carried by an occupant in the second crash.

Interiors have many design features to reduce the sources of injury. Padded dashboards that distribute forces,

TABLE 14-1 Federal Motor Vehicle Safety Standards (FMVSS)[a]

Number	Topic
CRASH AVOIDANCE	
101	Controls and displays
102	Transmission shift lever sequence, starter interlock, and transmission braking effect
103	Windshield defrosting and defogging systems
104	Windshield wiping and washing systems
105	Hydraulic and electric brake systems
106	Brake hoses
108	Lamps, reflective devices and associated equipment
109	New pneumatic bias ply and certain specialty tires
110	Tire selection and rims for motor vehicles
111	Rearview mirrors
113	Hood latch system
114	Theft protection
116	Motor vehicle brake fluids
117	Retreaded pneumatic tires
118	Power-operated window, partition, and roof panel systems
119	New pneumatic tires for vehicles other than passenger cars
120	Tire selection and rims for other than passenger cars
121	Air brake systems
122	Motorcycle brake systems
123	Motorcycle controls and displays
124	Accelerator control systems
125	Warning devices
129	New non-pneumatic tires for passenger cars—New temporary spare non-pneumatic tires for use on passenger cars
CRASHWORTHINESS	
201	Occupant protection in interior impact
202	Head restraints
203	Impact protection for driver from steering column system
204	Steering control rearward displacement
205	Glazing materials
206	Door locks and door retention components
207	Seating systems
208	Occupant crash protection
209	Seat belt assemblies
210	Seat belt assembly anchorages
212	Windshield mounting
213	Child restraint systems
214	Side door strength
216	Roof crush resistance
217	Bus emergency exits and window retention and release
218	Motorcycle helmets
219	Windshield zone intrusion
220	School bus rollover protection
221	School bus body joint strength
222	School bus passenger seating and crash protection
223	Rear impact guards
224	Rear impact protection
225	Child restraint anchorage systems
POST CRASH STANDARDS	
301	Fuel system integrity
302	Flammability of interior materials
303	Fuel system integrity of compressed natural gas vehicles
304	Compressed natural gas fuel container integrity
305	Electric-powered vehicles: Electrolyte spillage and electric shock protection
500	Low speed vehicles

[a]Refer to standards in 49 CFR 571 for current details and applicability to passenger cars, multipurpose passenger vehicles, trucks, buses and other vehicles (www.nhtsa.gov/cars/rules/import/fmvss/)

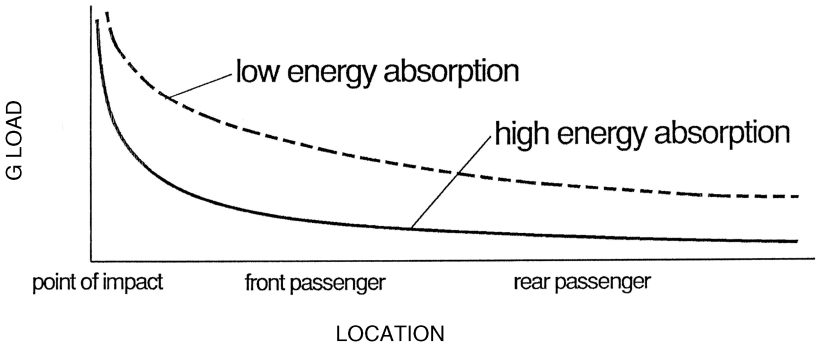


Figure 14-1. Approximate G loads from frontal impact as a function of distance from the point of impact.

laminated windshields that prevent imbedding glass in tissue, and elimination of protruding knobs and controls all reduce the probability of injuries. Energy-absorbing, collapsible steering columns significantly reduced the rate of injury to drivers during the second crash.

Crashworthiness

Crashworthiness refers to the ability of a vehicle to withstand an accident without intrusion of or reduction in the integrity of the passenger compartment. When a crash occurs, not only is it important to minimize the second crash, it is also important to ensure that the passenger compartment stays closed and retains its shape. The idea is to keep occupants inside a protected zone during a crash. Passengers thrown from a vehicle face a high risk of injury and death compared to those who stay inside.

Door latches and locks must stay closed during crashes. Doors must meet structural standards intended to provide compartment integrity in impacts, especially side impacts. The energy-absorbing steering column also reduces the injury caused by the steering column being driven into the driver's chest in a frontal crash. Compartment integrity also involves adequate structural strength to prevent roof collapse during rollover. The main energy absorption components of the vehicle are in vehicle elements outside the passenger compartment. Passenger restraints not only reduce the second crash, but keep people inside the protected zone. It is also important that fuel systems retain their integrity. If a fuel tank ruptures and spills fuel into the passenger compartment, the fuel can ignite. That reduces the opportunities for escape and rescue.

Crashworthiness and integrity of passenger compartments permit race car drivers to survive crashes at very high speeds. Special restraint features in race cars, including helmet restraints that protect the neck, have added to race driver safety. Many of the features tested in racing vehicles find their way into commercial vehicles. Crashworthiness has improved in most cars over the years. Improved design features have contributed to the reduction in crash injuries and occupant deaths.

14-2 CONTROLLING TRANSPORTATION HAZARDS

There are many factors that can and do contribute to the reduction of motor vehicle accidents and the resulting injuries and losses. In discussing controls, one can apply the models discussed in Chapters 3 and 9. For example, in discussing motor vehicles, the Four Ms representing man, machine, media, and management can refer to drivers, vehicles, roadways, weather conditions, regulations, enforcement, and cost. Haddon developed his energy management concepts from working with vehicle safety.

Vehicles

There are many safety features built into motor vehicles today. The National Highway Traffic Safety Administration sets safety standards for motor vehicles. They change over time. Table 14-1 is a summary of the Federal Motor Vehicle Safety Standards (FMVSS). The Society of Automotive Engineers (SAE) also publishes numerous standards for vehicles, including many safety standards. Vehicles include off-road vehicles and even golf carts. Other Department of Transportation agencies also establish vehicle safety standards. The Urban Mass Transportation Administration has safety standards for buses and rail vehicles and the Federal Highway Administration has safety standards for trucks. Industry associations, such as the Truck Trailer Manufacturer's Association, have also produced safety standards.

One device that has reduced injuries from the second crash and saved lives is the seat belt. Seat belts became mandatory in 1968. Initially there was only a lap belt. By the 1980s a combined lap belt and shoulder harness became the standard. Eventually, lap belts expanded to rear seats. The combined lap belt and shoulder harness eventually became the standard for rear seats. The belt designs fit adults. Infant and child seats slowly evolved so that adult belts served as the primary restraints for them. Additional belts systems in child seats provided restraint to the seat for a child.

Seat belt use grew slowly. Recent studies show that about 75–90% of automobile occupants wear seat belts.

CASE 14-1

May 18, 1988, Carrolton, Kentucky. A pickup truck struck a school bus filled with 62 teens, four chaperones and a driver. The group was returning from an outing. Two gasoline tanks on the bus ruptured. The spilled fuel burst into flames. Twenty-seven people died. Many others received severe burns. Only three escaped unharmed.

The driver of the pickup truck had a blood alcohol content (BAC) of 0.24, more that 1½ times the legal limit at the time. A court convicted him of manslaughter and sentenced him to 17 years in prison.

The case, which gained national attention, had several impacts. It helped reduce the legal BAC level in many states to 0.08. Because bus occupants could not escape through windows, the case influenced design standards for escape routes from buses and rupture-resistant gas tanks.[a,b]

[a] www.ntsb.gov/investigations/summary/har8901.htm
[b] www.dailymail.co.uk/news/article-2324709/Carrollton-bus-crash-25-years-deadliest-drunk-driving-crash-history-killed-27.html

There is no accurate measure of the injuries and lives saved by seat belts, but it is likely in the hundreds of thousands. Adding seat belt warning displays and sounds encouraged seat belt use.

Seat belt use has extended from automobiles to other vehicles. For example, operators of forklifts and airport tow tractors should wear seat belts to keep them inside the protected envelope surrounding the operator position. See Case 15-1.

An important design feature for trucks and cars is antilock braking systems (ABS). For years large aircraft had antilock brakes. Later, this technology moved to trucks and automobiles. The system senses the moment wheels lock up as static friction changes to sliding friction. Because the coefficient of sliding friction is normally less than the coefficient of static friction, the sensors interrupt braking for a fraction of a second. That allows a return to static friction, and then braking continues. This sequence repeats frequently until the vehicle stops.

Although invented in 1952, air bags did not gain full implementation until the 1990s. Today, passenger vehicles have driver side and passenger side air bags as standard equipment. Some adjustments in inflation rates have been made after performance data suggested that some adults and children received serious injuries during inflation. More recently, side air bags have appeared in interior roof lines of some automobile models to help minimize injury during side impacts. In 2014, there was a massive vehicle recall program involving air bags because the detonating device fragmented on occasion and caused injuries. However, air bags are effective and have saved many lives and prevented many injuries.

Some states require annual vehicle inspections to help ensure that vehicles and safety devices are in proper working order. The assumption is that vehicles with working headlights, brakes, and other features will improve highway safety. One study found no detectable impact on accident rates between states that required periodic vehicle inspections and those that did not. The main problem is that equipment failures may occur at any time, whereas inspections occur only once each year. Random inspections are about as effective as regular periodic inspections.

A trend started in the 2010s to incorporate smart or intelligent systems into vehicles. Various terms describe the new technologies: the autonomous car, piloted driving, and vehicle-to-vehicle (V2V) technology. The systems detect certain traffic conditions or situations and provide warnings or take over some driver functions. Some technologies manage braking, steering, and early decision-making. Most of these technologies address crash avoidance. Testing is underway for driverless automobiles.

Operators

There are many characteristics of drivers that affect the likelihood of an accident. Drivers must be licensed to operate a motor vehicle. They must pass written and road tests to receive a license. There is a renewal process.

The Federal Highway Administration sets minimum qualifications for drivers of motor carriers (commercial motor vehicles). Some of the qualifications include being 21 years old, meeting physical qualifications, knowledge of safe methods for securing cargo, passing road and written tests. Drivers may not qualify because of certain criminal or driving offenses (including driving under the influence of alcohol or drugs). The Federal Highway Administration (FHWA) continues to tighten driver qualification standards and expand training standards.

Well-trained drivers drive more safely than those with little or no training. Many states require high school students or those getting old enough to drive to take a driver education course before issuing a license. The value of high school

driver education is somewhat controversial. For example, one state dropped mandatory driver training as part of a high school curriculum. It found that the death rate among teenage drivers dropped. Much of the decline was due to a delay in the onset of driving. Instead of all students receiving a license at the earliest possible date, many did not begin to drive until after high school.

Another study compared three driver programs for 16,000 subjects. The three programs included a control group (no training), a normal training course, and a 70-hr intensive course. Then the study monitored driving records for accidents and violations. Results showed there were no significant differences in the overall mean rates of accidents or violations.

Many groups have addressed drunken driving in recent decades. Special groups formed, such as Mothers Against Drunk Driving (MADD) and Students Against Driving Drunk (SADD). They created a lot of public pressure that finally influenced the criminal justice system and sentencing for offenders.

There has been a national effort to change many laws governing alcohol and driving. Many states have raised their legal drinking age to 21 years. In 1987, the Supreme Court upheld the federal law that restricted federal funds to states that did not comply with a set legal age for purchase of alcoholic beverages. Where states have raised the drinking age to 21 years, one study found a reduction of 13% in nighttime motor vehicle deaths. Employers have become stricter with employees who drink and drive while on duty. One study showed that in the early 1980s, 15–16% of fatally injured tractor trailer drivers tested had BACs of 0.10 or greater. By 1986, only 3% had BACs that high.

Another trend is use of technology to influence driver behavior. There are sensors to detect the blood alcohol level of a driver and lock out the ignition if the level is too high. There are camera systems that monitor whether drivers exceed speed limits or fail to stop at intersections. Some photo enforcement applications are controversial.

Facilities

The Federal Highway Administration (FHWA) specifies highway design standards and traffic control devices. The *Manual on Uniform Traffic Control Devices*[6] (MUTCD) provides details on signage, traffic lights, lane markings, traffic and separation devices, and other items. State agencies adopt and supplement these standards.

The FHWA approves many standards as acceptable for design of highways and roads.[7] Most are standards of the American Association of State Highway and Transportation Officials (AASHTO).[8] State highway departments approve standards for their states.

A few examples of design features that have improved the safety of highways include break-away light poles, break-away signs, energy-absorbing guardrail ends, divider barriers, and protected bridge supports. A more recent design feature for multi-lane highways are cable barriers between opposing traffic lanes.

In the early days of interstate highway design, the bases for light poles were heavy concrete structures that simply stopped a vehicle upon impact. Today the bases are much smaller. Signs have anchors that shear and separate the pole from the base when struck by a vehicle (see Figure 14-2). Highway construction uses the same break-away technology for highway signs (see Figure 14-3).

Guardrails are a common design feature for major highways. Initially, guard rails had an end at the same height as the rest of the guardrail. When a vehicle struck the end of the guardrail just right, the guardrail entered the windshield and pierced through the passenger compartment. Today the ends of some guardrails extend below ground level. Others have a telescoping, energy-absorbing segment at the impact end. Figure 14-4 illustrates some guardrail features.

Early interstate highway designs had a variety of protective barriers. Later experience and research led to better barrier designs that prevent vehicles of various sizes from overriding them. That led to a standard barrier with a unique cross-sectional shape (see Figure 14-5). These barriers provide protection for permanent bridge construction and lane separation when there is little distance between opposing lanes. Many highway construction project use the barriers to create safe work zones for workers.

Early interstate highway designs left unprotected those bridge supports and columns located at some distance from the pavement. The columns were immoveable when struck. Occasionally, people used them to commit suicide by driving into them at high speeds. Today, energy-absorbing barriers containing sand or water, guardrails, and concrete barriers provide protection. Figure 14-6 illustrates protection of bridge piers.

A relatively new highway design feature is a cable barrier.[9] Uses include median barriers and protection of transitions for guardrails and other structures. For certain kinds of opposing lane separations, the barriers provide a way to prevent vehicles from crossing into opposing lanes. Several states have adopted cable barriers into their highway designs. Figure 14-7 shows an example.

Environments

Traffic safety environments include such factors as time of day, weather conditions, pavement conditions, and other factors. Based on travel rates, accidents occur more frequently at night. Drivers may have greater fatigue at night. The proportion of drivers who have been drinking is higher.

Other factors contribute to nighttime highway safety. Lighting of highways, particularly intersections, reduces accident frequency. Headlights must be effective. Light

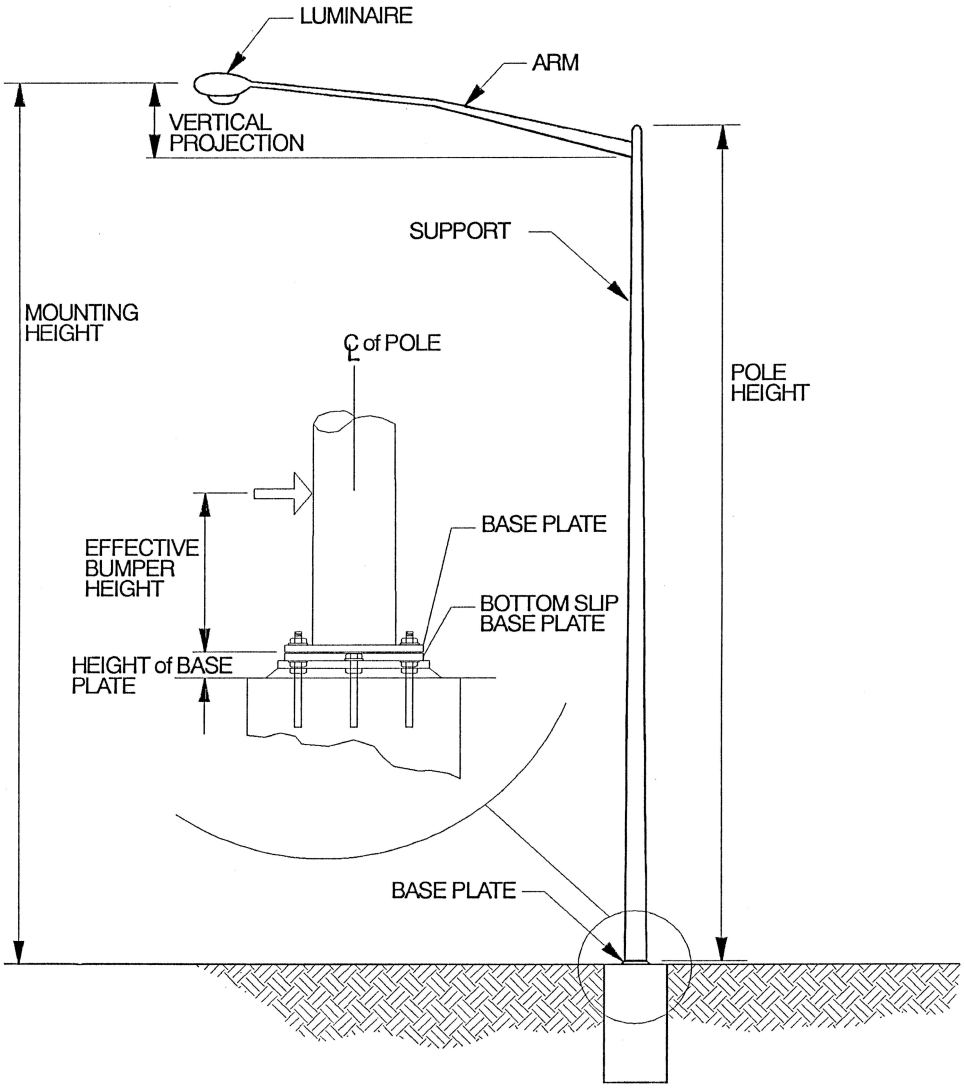


Figure 14-2. Design for break-away light poles.

from headlights diminishes with the square of the distance from the vehicle. A driver has a limited amount of time to react and stop the vehicle after seeing an object in the distance. For a particular speed, the distance needed for object perception, reaction, and stopping must be less than the effective distance for headlights. Wearing sunglasses, having tinted windows, or vision impairments will reduce the effective distance.

Falling rain and snow can hinder visibility. Wet roads and roads covered by ice and snow reduce friction between the tires and the pavement. Consequently, cars cannot stop as quickly or maneuver as well. Grooves built into the pavement will improve traction on wet roads.

Pavements normally have some amount of crown to allow water to drain and to prevent pools to form. If water accumulate on the pavement, hydroplaning can occur. In hydroplaning, a film of water separates the tires from the pavement, reducing friction even further. To enhance traction on wet pavement, tires have grooves in the tread pattern and sipes (cuts or narrow slots in the tread design that allow the tire to flex in small elements). Both tire grooves and sipes allow water to move on the tire surface and help prevent hydroplaning. Worn tires lose much of that capability.

Governments in northern climates spend large amounts of money to keep highways clear in winter weather. Snow fences keep drifting snow from accumulating on highways and roads. Crews plow the snow and salt pavements. The salt lowers the melting point of snow and ice. That allows for drainage, removal, or evaporation. Special tread designs on tires can increase traction, particularly for snow conditions, but have a limited effect on ice. For a while people could buy studded tires to improve traction. However, damage to pavements resulted in laws banning them. In severe snow and ice conditions, chains provide improved traction, but

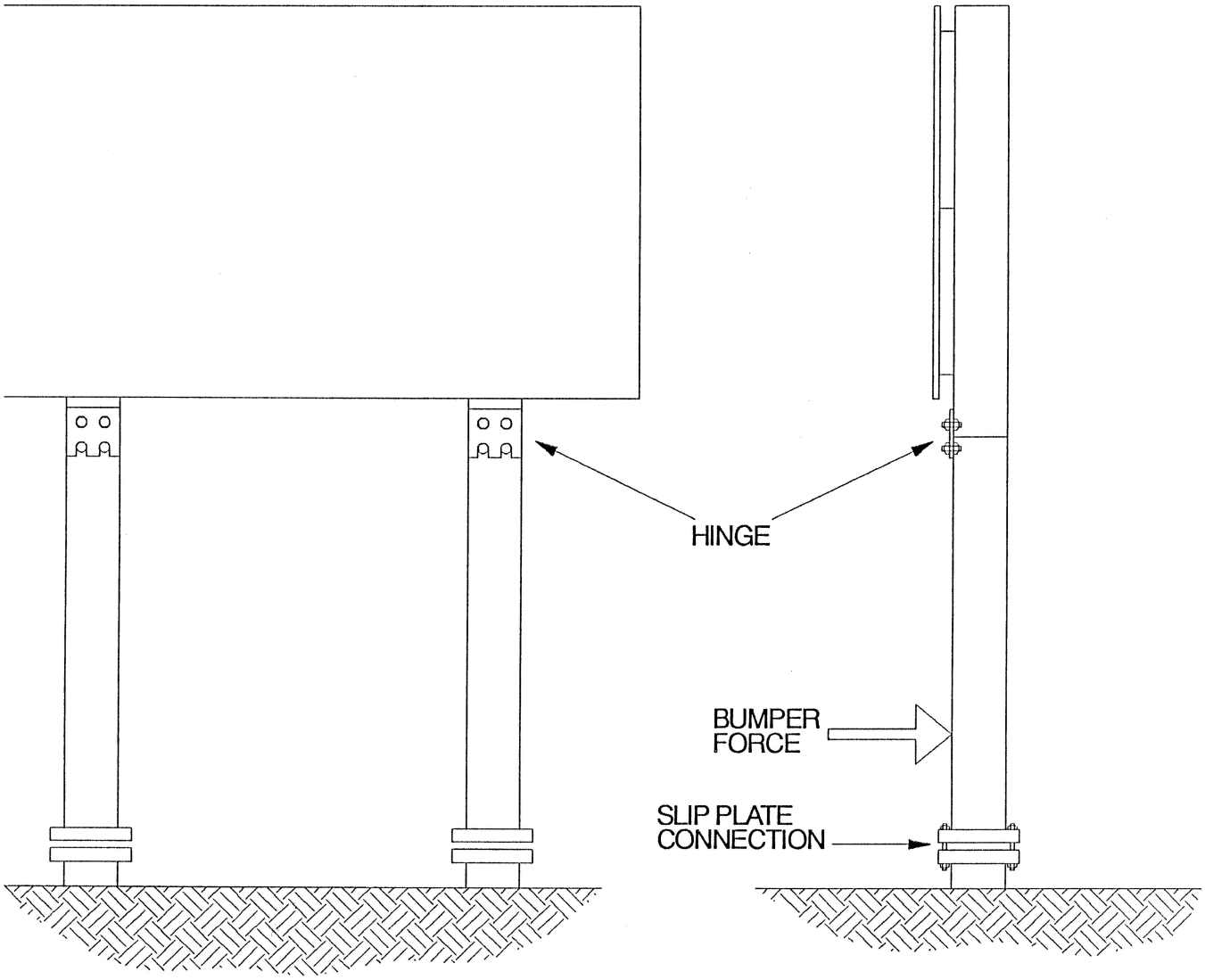


Figure 14-3. Design for break-away highway signs.

destroy vehicle ride, create vibration and noise, and damage pavements. Some mountain roads require chains at certain times.

Other highway conditions might include shoulder width. Where there is little room between the pavement and a ditch, there is little room to maneuver out of a dangerous situation. There is no escape zone.

Traffic density, merging traffic, and visual distractions are factors of the environment related to vehicle accidents. Trees, bushes, and buildings that obscure intersections and people or vehicles emerging from driveways and yards are environment conditions, too. Community zoning ordinances often control setback of buildings, vegetation, fencing, and other obstruction from roadways to help assure visibility.

Recently, distractions of various kinds have received increasing attention. Cell phones, global positioning displays, video and DVD players, and other built-in or driver-carried equipment may contribute to distractions. They are grouped into visual, auditory, or cognitive distractions. Additional studies may help understand the effects of the growing number of in-vehicle equipment items. Eating, drinking, smoking, reading, putting on make-up, and similar activities while driving also impact driver attention, control, errors, reaction times, and stopping times. Already some government entities have banned texting and cell phone use and other distracting activities in driving. Texting is a both a visual and cognitive distraction. It contributes significantly to serious accidents. Distractions of all kinds can affect driver error rates and performance.

Social, Political, and Managerial Context

In the social, political, and managerial context, there are many laws and regulations governing drivers, pedestrians,



Figure 14-4. Example of an energy-absorbing guardrail (the QuadGuard® system). Telescoping sections collapse when impacted and crushable, foam-filled cartridges absorb energy. (Photo provided by Quixote Corporation, Chicago, IL.)

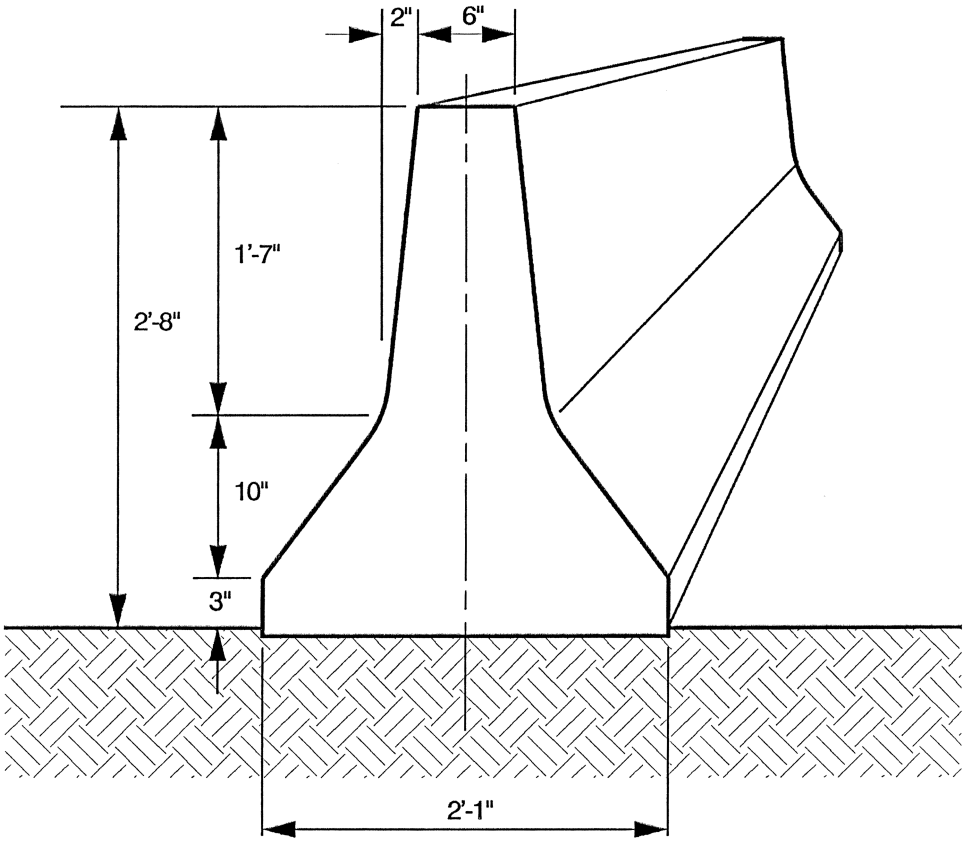


Figure 14-5. Concrete barriers provide protection for highway workers in construction zones, separate opposing traffic lanes and form bridge guardrails.



Figure 14-6. Example of sand-filled plastic barrels (the Energite III® inertial barrier system) that protect vehicles from impacting bridge columns and other objects near highways. (Photo provided by Quixote Corporation, Chicago, IL.)

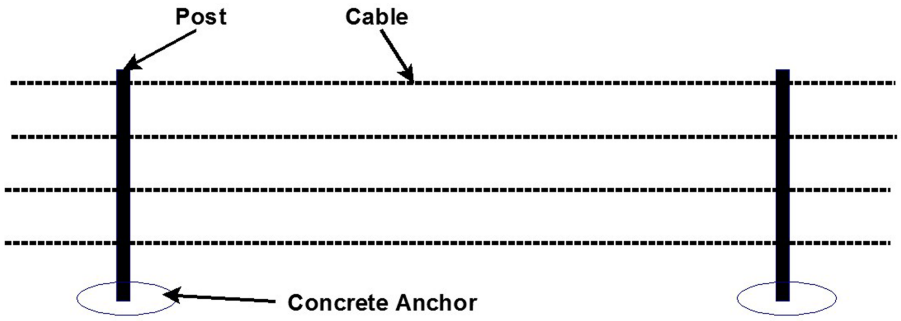


Figure 14-7. Basic components of cable barriers that protect against median crossover between opposing lanes of traffic.

driving employees, and others. Social pressures to drink or take drugs and drive are part of the context. Traffic problems increase in rapidly growing communities with insufficient funding to develop roadways to meet traffic loads. Lack of funds to maintain roadways and lack of standard laws, signage, and traffic procedures can contribute to accidents.

There is some discussion about which approach to vehicle safety is most effective. Traffic safety in the U.S. has focused and continues to focus on technology to reduce deaths and injuries after a crash. Much of Europe has emphasized changing driver behavior to prevent crashes. Both approaches have reduced traffic deaths a lot. While the reduction in the U.S. during the last 40 years was 41%. In Germany, the Netherlands, and Great Britain, the reductions were 81%, 81%, and 76%, respectively.[10] Those considerations and vehicle accident and death facts suggest that much work remains.

14-3 ACCIDENT RECONSTRUCTION

Accident reconstruction is the process of collecting evidence from a vehicle accident to determine what happened. The evidence helps determine what may have caused the accident. Over the years, engineers have developed several analytical techniques. There are many commercial computer programs that store, compile, and analyze data about particular accidents.

In accident reconstruction, someone first collects data at the accident scene. There are records of each type and model of vehicle There are photos and records of other data about the damage to each vehicle. There are records or plots of skid marks, impact points, final locations of vehicles, and vehicle components. There are records of pavements and surfaces involved in the accident. Investigators can log many of these data items directly on portable computers and devices. Often police record these data as part of on-scene reports.

From the compiled data, equations applying conservation of energy and conservation of momentum allow one to estimate the speed of vehicles before the crash. Analysis can show which vehicle was in which position at the point of impact and produce other information. Vehicle damage and examination of remaining components also suggest whether equipment, such as lights and brakes, operated properly. Other observations may suggest defects in the vehicle.

Software often include reference data files of mass and damage data by vehicle make and model. Most programs prepare graphic plots of the vehicle positions before, during, and after a crash overlaid on skid, pavement, and other site data. Some software products incorporate information for aerodynamic drag and disturbances, engine drag, tire rolling drag and lateral force, steering maneuvers, braking effects, impact models, and interrelationships among some of these. Results from computer modeling of crashes are accurate if there are accurate data from an accident scene.

Some simple examples of accident reconstruction analysis will illustrate the approach. One can compute stopping distance s, in feet, for full, four-wheel braking of an automobile, from

$$s = V^2/30\mu \tag{14-1}$$

where

V = initial velocity (miles per hour)

μ = coefficient of friction for the tires on the pavement

Using Equation (14-1) one can estimate the initial speed of a vehicle from skid marks, where the vehicle skidded to a full stop.

If only two or three wheels were skidding, an additional factor n is introduced into Equation (14-1):

$$s = V^2/30\mu n \tag{14-2}$$

where

$n = 0.75$ for three wheels braking

$n = 0.50$ for two wheels braking

The total stopping distance is

$$S_p = \text{prebraking distance} + \text{stopping distance} \tag{14-3}$$

The prebraking distance includes perception time plus reaction time. Perception time is the time for recognizing that one should start braking. Reaction time is the time necessary to move the foot onto the brake pedal and begin braking.

In front and rear collisions, one can estimate vehicle velocities by applying conservation of momentum. The momentum for two colliding vehicles before a crash must be equal to that after a collision:

$$(W_1V_1) + (W_2V_2) = (W_3V_3) + (W_4V_4) \tag{14-4}$$

where

W = weight (pounds)

V = velocity (miles per hour)

subscripts 1 and 2 represent the two vehicles before the crash

subscripts 3 and 4 represent the two vehicles after the crash

One must know vehicle weights and vehicle speed before or after the crash to solve this equation.

Example 14-1 Consider a rear-end collision between two vehicles. Vehicle 1 weighs 3500 lb and vehicle 2 weighs 2800 lb. Vehicle 1 is standing still at a stop light and the driver has the brakes fully engaged. Vehicle 2 crashes into it. Just at the point of impact, the second vehicle begins to skid. The two vehicles skid 25 ft beyond the point of impact, with all wheels locked. Assume the coefficient of friction between the dry pavement and tires is 0.85. How fast was the second vehicle going before the accident?

The velocity of vehicle 1 is zero before the crash and there is no change in the weight of the vehicles from before to after the crash. Using Equation (14-4),

$$(3500 \times 0) + (2800 \times V_2) = (3500 + 2800)V_3$$

V_3 is determined from Equation (14-1):

$$V_3 = (30 \times 0.85 \times 25)^{1/2} = 25.25 \text{ mi/hr}$$

Then

$$V_2 = 6300(25.25)/2800 = 56.8 \text{ mi/hr}$$

14-4 OTHER FORMS OF TRANSPORTATION

Railroads

Since their emergence in the mid-1800s, railroads have faced safety problems. In the rush to complete the transcontinental railroad in 1867, safety received limited attention. In 1888, 315 passengers were killed and 2,138 were injured. In the same year 2,070 employees were killed and 20,148 were injured. One citizen, a farmer from Iowa named Lorenzo Coffin, was so irate that he launched his own campaign for railroad safety. His efforts led to enactment of the Rail Safety Appliance Act of 1893. The act required the use of two inventions. One was the Westinghouse airbrake, which replaced manual brakes on the top of each car. The other was the Janney coupling, which replaced the oval links and pins. After several years, railroad employee accidents dropped by 60%. Soon the railroads learned that safety of both employees and passengers paid dividends in cash and good will.[11]

Another significant improvement was an automatic block signal system that kept trains from colliding on the same track. Also, boiler overpressure valves prevented steam engines from exploding.

Hazards The safety record of railroads has improved significantly. The hazards have changed. Today derailments pose significant hazards from the transported materials, including explosions, fires, and releases of toxic materials. The majority of rail deaths and injuries now result from grade crossing accidents with motor vehicles.

CASE 14-2

One of the jobs of a railroad brakeman or trainman in the 1870s was coupling and uncoupling cars. Before the introduction of couplings in use today, railroads used a link and pin system. Each end of an elongated link went horizontally into a slot in a wood or metal extension on each car. A pin fit vertically through a hole in each extension and through one end of the link. The pins depended on gravity to stay in place.

A brakeman had an inherently dangerous job. He stood between cars during coupling. He lifted the loose end of a link into the extension on another car and dropped a pin into place. The activity led to the loss of countless fingers and hands. At times brakemen became crushed between cars.

Records show that in 1893, the year the Federal Rail Safety Appliance Act passed, 310 trainmen were killed and 8,753 were injured in coupling-related accidents. The new law eventually led to the use of automatic couplings.

Brakemen also climbed to the top of a car to turn a wheel that set the brake for that car. Brakemen often slipped and fell from atop the cars. This contributed a lot to the injury and death rate of railroad workers.[a]

[a]www.wcrscorp.com/resources/frsafety.pdf

Controls Today's railroad cars incorporate many safety features. There is no need to climb atop a car to set brakes, since air pressure operates all car brakes in a train. For certain loading and unloading operations, some cars have ladders. Ladders have rungs that prevent feet from sliding off. There are grab bars at climbing transition points and slip-resistant walkways and handrails. Thermally insulated tank cars prevent heat buildup and explosions from fires in adjacent cars. Cars carrying hazardous materials have interlocking couplings so they do not unhook easily. Locomotives have deadman controls to prevent runaway trains should an engineer become incapacitated. Cars containing hazardous materials have placards indicating contents and type of hazard. Automatic sensors placed strategically along main lines detect over-heated bearings. These are some of the current controls.

Based on traffic at crossings, more and more grade crossings have barrier gates and signals. Sensors that detect the speed of a train activate gates and assure adequate lead time for gates to close. However, there are drivers who try to go around gates. Some infrequently used grade crossings do not have signals and gates. Some have overgrown vegetation that reduces visibility.

Major highways avoid grade crossings by using underpasses and bridges. Some cities have diverted main line rail traffic from the inner cities where dangerous traffic conflicts exist.

Aviation

The worldwide aviation industry continues to grow at a rapid pace. There is an increase in both commercial aircraft and private aircraft. Most propeller-driven aircraft have given way to jet-powered aircraft. Some commercial aircraft are large, carrying 500 or more passengers. Airways grow more crowded. The number of takeoffs and landings nearly doubled in one decade.

The commercial aviation safety record is very good and continues to improve worldwide. The number of deaths

CASE 14-3

July 6, 2013, Lac-Megantic, Quebec. An unattended 74-car freight train carrying Bakken crude oil ran away and derailed in the downtown area of Lac-Magantic. The incident was one of the worst railroad disasters in Canadian history. A huge fire and multiple explosions resulted. Officials evacuated about 2,000 people to shelters. The incident left 42 people confirmed dead and 5 others missing. The event destroyed more than 30 buildings in the town center.

The case involved a complex sequence of events. Investigations pointed to many issues, including flawed operating procedures, driver error, a defective locomotive, poor track maintenance, weak regulatory oversight, and lack of safety redundancy.[a,b]

Bakken (North Dakota) crude oil was also an issue. Unlike some other sources of crude oil, Bakken crude contains more dissolved gas. That makes it more flammable.

This incident and related ones have led to demands for improved railroad tank car designs.

[a]www.tsb.gc.ca/eng/rapports-reports/rail/2013/r13d0054/r13d0054-r-es.asp

[b]www.theglobeandmail.com/news/national/lac-megantic-report-18-things-that-went-srong/article20110506/?from+20129764

CASE 14-4

March 24, 2014. Chicago, IL. An eight-car Chicago Transit Authority (CTA) commuter train arrived at the O'Hare International Airport terminal. The train ran through an end-of-track barrier and continued up an escalator. There were injuries to 32 people. Because the accident occurred at 3 a.m., there were few serious injuries and no deaths. During daylight hours, many people would have occupied the terminal, escalator, and platform above.

This case had complexities. The train operator reported having dozed off before the crash. The operator had a long, weekend work schedule. There was no automatic braking system at the station as a backup for an operational failure. The terminal design placed the escalators directly in line with the end of the tracks. Many station escalators are in line with loading and unloading platforms offset from tracks.

This was a dramatic event causing about $6 million in damage. A video camera recorded the event on fixed cameras in the terminal.[a,b]

[a] www.youtube.com/watch?v=elMXt00xyIU
[b] www.youtube.com/watch?v=-k-fYYyN8nM

based on miles traveled or rate of take offs and landings is very low. In 2013, the world's airlines had 29 accidents resulting in a record low of 265 fatalities. There were 36.4 million flights for 2.4 billion passengers without incident. By 2013, U.S. major airlines had achieved nearly a decade of flights without killing a single passenger.[12]

U.S. business jets also have reduced accident rates. In 2013, there were six fatal accidents and 17 fatalities.

Hazards Aircraft must take off and land without incident. With increased crowding of airspace in some areas, sophisticated electronic gear helps control the traffic and fly the aircraft in the highways of the air. Aviation hazards have changed with aircraft scale, speed, and altitude. Higher structural loads require exotic, lightweight, and strong materials. Examples are fiber-reinforced titanium and carbon fiber and epoxy composite. Structures face fatigue from expansion and contraction during repeated loading, pressurization and depressurization, and from thermal expansion and contraction.

A large portion of an aircraft's takeoff weight is fuel. Leaking fuel tanks and ignition can be disastrous. Icing of wings and resulting loss of lift are still a danger in severe weather. Designing emergency exiting for as many as 500 passengers is a challenge. Detecting and avoiding wind shear that leads to sudden altitude changes, particularly in clear weather, also remains a challenge.

There are many other hazards for aircraft and aviation operations. One growing issue involves automation for aircraft. There are opportunities for error. Systems may reduce pilot attention and overload training needs. Built-in software and data errors can lead to flight irregularities and crashes. For example, in Australia, a pilot keyed the wrong load data into a computer, overloading a plane by several tons. Pilots of an Asiana Airlines flight that struck the end of a runway at the San Francisco International Airport on July 6, 2013, had little training in manual control of the aircraft. They made errors in aircraft speed after shutting off the autopilot. Their training covered automated landings primarily.

Another growing hazard is ground-operated lasers pointed at aircraft that blind pilots temporarily. Studies have identified a significant rate of air traffic controller errors that rely on human capabilities.

Controls The newest aircraft have on-board computers and instruments for navigation, flight control and management, fuel management, fire detection and extinguishment, collision avoidance, pressurization control, and many other functions. Many have automatic landing capabilities. There is a need to continually upgrade air traffic control systems to handle increased traffic. Without these systems, aviation would not be possible or as safe as it is.

Federal Aviation Administration regulations set design standards and control airworthiness of the aircraft and its engines. Flight and maintenance logs help ensure that equipment is in good condition. However, new technologies incorporated into aircraft require updates to procedures for qualifying aircraft for flight. Regulation of pilot training and certification place qualified crews in charge of flights. Standards and continuous training for air traffic controllers are essential, too. Airlines and aviation employee unions set standards for employee qualifications. Strict management and enforcement of flight and operation regulations and procedures contribute to aviation safety.

Most commercial airlines have introduced and use safety management systems, SMS (see Chapter 35). The concept helps ensure that all elements of an organization understand and apply risk assessment methods and make decisions that reduce the potential for errors, accidents, injuries, and death.

Pipelines

Pipelines transport gases and liquids. Most materials transported by pipeline are fuels. Included are natural gas, liquified natural gas, and other petroleum products. Other hazardous materials, such as anhydrous ammonia, also move through pipelines. Department of Transportation regulations govern pipelines.

Other piping systems transport water, storm runoff, sanitary waste, and other wastes. Government standards for water and waste fall under Environmental Protection Agency (EPA) regulations and state and local codes.

Hazards Because most pipelines are underground, there are hazards related to materials handling and excavation during construction and repair.

For pipelines carrying fuels and hazardous materials, pumping systems move contents from sources to processing and use locations. Fire and explosion are major concerns for fuels and flammable materials. A leak in a pipe, fitting, valve, pump, or other component of a pipeline can produce disastrous results. During maintenance, workers must depressurize, block off, and purge segments under repair to prevent ignition of any residual fuel. They must close valves and lock them before working on flanges. If material in a pipeline is corrosive or toxic, there are contact and inhalation dangers. Gaskets and packings in valves are common failure points.

Pipelines have special facilities. They include pumping stations, storage tanks, collection stations, and transfer stations. Most are above-ground facilities and part of the pipeline systems. Physical damage, corrosion, and component failures can lead to major disasters. Opening the wrong valve and not knowing what is in a system are common errors.

A failure in a pressurized water system will not have nearly the same results as piping systems for flammable or toxic materials. Storm and sanitary systems depend on gravity to move the contents. Leaks may contaminate underground water sources and leaking material may leach to the surface or into water supplies and create health hazards.

Underground storage tanks create leak hazards. Hazardous materials create much concern. The EPA regulates and sets standards for underground storage tanks.

Controls Pipelines and facilities for fuels and hazardous materials that are under pressure must meet the strict design standards of the Department of Transportation (DOT). Standards vary for different pipe materials and different materials transported. Pressurized pipelines and fittings require pressure testing before initial use and following repair. The DOT also specifies detailed requirements for operation, maintenance, inspection, and reporting procedures. DOT standards related to pipelines incorporate standards of other organizations, including the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), and the American Society for Testing and Materials (ASTM).

Piping and components should have labels to prevent errors in contents. Labels also identify what each component does. There are standards for pipe labeling. Maintenance of pipelines, components and facilities requires detailed planning, communication among workers, and application of many safety procedures. For example, failure to remove the pressure from a pipeline and to purge residual fuels can lead to explosion, severe injury, and fire. Welding in the presence of residual fuels is dangerous. A box or hood placed on valve stems can prevent injury and damage when a valve packing blows.

Multiple crews working on the same segment must have close communication. This is most important when the crews are far apart. One crew may not know precisely what the other is doing. For example, one crew may operate a compressor and pressurize the pipe to begin pressure testing. The other crew may assume there is no pressure in the pipe. The second crew may have work continuing that explodes and causes injury.

14-5 TRANSPORTATION OF HAZARDOUS MATERIALS

The Transportation Safety Act of 1974 recognized the dangers to life and property that can result from the transportation of a variety of hazardous materials. If there is an accident, a spill of materials could create significant harm for passengers, other vehicles nearby, and people living near the accident. The act applies to transportation, shipping, packaging, and labeling of materials defined as hazardous, and it provides for penalties for violations. Estimates suggest there are more than 250,000 hazardous material shipments every day in the United States. Estimates also suggest at least 400 shipments per year involve injury accidents.

Hazards

The Transportation Safety Act defines several classes of hazardous materials. Classes include explosives, radioactive material, flammable liquids or solids, combustible liquids or solids, oxidizing or corrosive materials, compressed gases, poisons, etiologic agents (hazardous biological materials), irritating materials, and other regulated materials (ORM). The act excludes firearms and ammunition. Other chapters in this book discuss hazards associated with some of these materials.

Controls

To minimize the danger to life and property, controls for hazards fall into several categories. Controls include defining and recognizing hazardous materials, excluding certain

materials from particular transportation modes, limiting quantities, controlling placement, design and selection of packaging, labeling of containers, restricting transportation routes, using shipping manifests, incident reporting, and training.

Definition and Recognition The U.S. Department of Transportation (DOT) defines which materials are hazardous. The agency organizes the materials into classes and divisions. Table 14-2 lists the classes and divisions for hazard materials. DOT works with other agencies to maintain a list of several thousand hazardous materials. The Pipeline and Hazardous Materials Administration publishes the list in 49 CFR 172.101.[13] The table includes material names, classes and divisions, labeling and packaging information, quantity limitations by transportation mode, and other information. DOT updates the list regularly.

DOT standards also assure harmonization with UN Recommendations on the Transport of Dangerous Goods by air and water.[14]

Those who transport or use hazardous materials must know which materials are hazardous. Training and labeling help convey this information. DOT publishes guidance on use of its standards.[15]

Excluding and Isolating Material No radioactive material may be carried or shipped by aircraft. There are restrictions on certain materials and quantities on passenger aircraft or passenger railroad cars. Some hazardous materials cannot be in the same shipment with certain other hazardous materials.

Limiting Quantities Another way to limit the dangers of hazardous materials is to limit the quantity present in containers or in transport. For example, someone may carry very small quantities of certain materials onto passenger aircraft. Regulations permit larger amounts on cargo aircraft and even greater amounts by rail, truck or water vessels. There are potentially large fines for violations. Consider a case in which an employee of a chemical company carried a small container of nitric acid in his luggage. The acid spilled and damaged the aircraft baggage compartment. The employee's company received a $15,000 fine.

Storage Rules Hazards of some materials increase if they come into contact with other materials. For example, a fire involving flammable materials will greatly intensify in the presence of an oxidizer other than air. Some chemicals will react violently when mixed with water or other materials. The

TABLE 14-2 DOT Hazardous Materials Classes and Divisions[a]

49 CFR Class	Division	Definition	Name of Class or Division
None		173.21	Forbidden materials
		173.54	Forbidden explosives
1	1.1	173.50	Explosives (with a mass explosion hazard)
1	1.2	173.50	Explosives (with a projection hazard)
1	1.3	173.50	Explosives (with predominately a fire hazard)
1	1.4	173.50	Explosives (with no significant blast hazard)
1	1.5	173.50	Very sensitive explosives, blasting agents
1	1.6	173.50	Extremely insensitive detonating substances
2	2.1	173.115	Flammable gas
2	2.2	173.115	Non-flammable compressed gas
2	2.3	173.115	Poisonous gas
3		173.120	Flammable and combustible liquid
4	4.1	173.124	Flammable solid
4	4.2	173.124	Spontaneously combustible material
4	4.3	173.124	Dangerous when wet material
5	5.1	173.127	Oxidizer
5	5.2	173.128	Organic peroxide
6	6.1	173.132	Poisonous materials
6	6.2	173.134	Infectious substance (Etiologic agent)
7		173.403	Radioactive material
8		173.136	Corrosive material
9		173.140	Miscellaneous hazardous material
None		173.144	Other regulated material: ORM-D

[a]See 49 CFR 173.2. (www.ecfr.gov/cgi-bin/text-idx?SID=5b3bf2d578e00862e79d7c90ebbed447&node=se49.2.173_12&rgn=div8).
For details on specific hazardous materials definitions and associated data for each, refer to the Pipeline and Hazardous Materials Safety Administration listing: www.phmsa.dot.gov/portal/site/PHMSA/menuitem.6f23687cf7b00b0f22e4c6962d9c8789/?vgnextoid=d84ddf479bd7d110VgnVCM1000009ed07898RCRD&vgnextchannel=4f347fd9b896b110VgnVCM1000009ed07898RCRD



Figure 14-8. Examples of DOT warning placards.

hazardous materials table gives guidance on placement of materials. Standards do not allow some materials in locations where people are normally present. Some require separation from other materials during storage and transit. Some materials must be kept dry, cool, away from sunlight or heat, or meet other restrictions.

Packaging Design and Selection DOT has many standards for the design of packaging. Regulations specify strength, dimensions, and other properties for fiberboard boxes and drums, glass carboys, steel drums and liners, tank trucks, rail tank cars, and many other containers. Regulations also specify what type of containers to use for each hazardous materials. The major purpose of these design standards is to minimize the release of hazardous materials, even if the packaging is in an accident. To dramatize the value of hazardous material packaging, the British government placed a shipping container for nuclear fuel rods on a railroad track and crashed a train into it at 100 mph. The container withstood the crash without a leak.

Labeling Serious errors in the transport and handling of hazardous materials could occur when people involved do not know what is in containers. DOT has many regulations regarding labeling of particular materials. Typically, a label indicates which material is inside a container. Labels also give warnings for handling and transport. Labels identify the DOT hazard class and division and other special information.

Many empty containers must have an "EMPTY" label. For some materials there are dangers for an empty container that do not exist when it is full.

As part of the labeling, DOT requires a standard warning placard. Trucks, freight containers and rail cars must have placards listing the class of hazardous material by name and symbol. For some materials, a placard must also list the name of the material and a DOT identifying number. Some labels include a United Nations Hazard Class Number.[16] Figure 14-8 gives examples of DOT warning placards.

Restricted Transportation Routes Some states have laws that restrict the highways over which certain hazardous materials can travel. Restrictions often occur where there are high densities of people and highly traveled or critical tunnels and bridges. In addition, local ordinances may restrict transportation of hazardous materials. Some state and local restrictions have resulted from public reaction to disasters.

Shipping Papers DOT regulations require that a shipping order, bill of lading, manifest or other document used to initiate a shipment must describe any hazardous material offered for shipment. The description must include the name of the material, the DOT hazard class and division, the

CASE 14-5

June 21, 1970, Crescent City, IL. Following a derailment in the center of this small town, a tank car containing LP gas caught fire and exploded. The explosion destroyed most the town's businesses.[a] The explosion was a boiling liquid expanding vapor explosion, BLEVE (see Chapter 17).

[a] www.youtube.com/watch?v=ic-YJYb7xL8

amount shipped, and the number and type of containers. The document must separate hazardous materials from other materials. The shipping papers must certify that hazardous materials meet packaging and labeling standards. There are additional requirements for hazardous waste.

Incident Reports During transportation a carrier must report to DOT any unintentional release of a hazardous material. When an incident involves death, serious injury, major property damage or certain releases of radioactive and etiologic agents, the carrier must make an immediate telephone report. DOT regulations detail these reporting procedures.

Training To help minimize the release of hazardous materials, people in the entire transportation chain must receive training. Designers of packaging, preparers of shipments, managers of shipping and handling, drivers, operators, and handlers need to know the dangers of the materials and the procedures to assure safety. DOT requires each person who offers hazardous materials for transportation to instruct officers, agents, and employees about applicable regulations.

EXERCISES

1. A car skids to a stop. At the start of the skid, the car was traveling 50 mi/hr. What was the stopping distance if the coefficient of friction between the tires and the pavement was 0.71?
2. An investigator finds skid marks 90 ft long. If the skid brought the car to a stop, what was the initial velocity of the car? Assume a coefficient of friction of 0.65 between the tires and the pavement.
3. For the situation in Exercise 2, what was the initial velocity if only two wheels were sliding and the braking efficiency was 0.5?
4. For the situation in Exercise 2, what was the total stopping distance, if the driver's combined perception and reaction time was 0.65 s? Assume the vehicle weights 1000 lb.
5. Car 1 waits at a stop light with brakes locked. Car 2 skids and strikes car 1 in the rear. If, after the collision, both cars skid 60 ft to a stop and the coefficient of friction is 0.45 for a wet pavement, what was the velocity of car 2 at the time of impact? Car 1 weighs 2500 lb and car 2 weighs 3800 lb.
6. A forklift industrial truck turns a corner with a 1000 lb load on the forks. The forks are raised 3 ft above the floor. The center of gravity for the forklift with driver is 38 in. above the floor with empty forks at the floor. The center of gravity of the load is 22 in. above the floor when it sets on the floor. The forklift weighs 2800 lb. Its wheels are 48 in. between lateral outside edges. If the radius of turn is 25 ft, the speed of the forklift is 8 mi/hr and the coefficient of friction between tires and floor is 0.67, will the forklift turn over, skid, or negotiate the turn?
7. Locate consensus or government safety standards for each of the following. Select one design feature that contributes to safety for each and describe its function.
   (a) motor vehicles
   (b) school buses
   (c) truck tractors
   (d) truck trailers
   (e) highways
   (f) railroad cars
   (g) railroad traffic controls
   (h) aircraft
   (i) pipelines

REVIEW QUESTIONS

1. About how many people die each year on United States highways? On roads, globally?
2. What is the leading cause of occupational injuries and work-related deaths?
3. The motor vehicle death rate is highest for which age groups?
4. Describe the crash sequence for a vehicle and its passenger
   (a) in a frontal crash
   (b) in a rear-end collision
5. What is the "second crash?"
6. Describe the concept of crashworthiness.
7. What is meant by integrity of the passenger compartment?
8. Which organizations publish standards for motor vehicles?
9. Describe a safety feature built into a motor vehicle.
10. Describe a driver characteristic important for motor vehicle safety.
11. Describe a design standard for highways that reduces injury or death.
12. Describe an environmental factor that contributes to motor vehicle safety.
13. What is accident reconstruction?
14. Name two hazards in rail transportation today.
15. Name four safety design features in railroad cars.
16. Name two factors that contribute to aviation safety.

17. Identify four controls for hazards of pipelines and related facilities.
18. What types of controls reduce the dangers associated with transportation of hazardous materials?

NOTES

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CHAPTER 15

MATERIALS HANDLING

15-1 INTRODUCTION

Materials handling is the lifting, moving, and placing of various kinds of items. It may be done manually or with equipment. Materials handling includes the use of many kinds of equipment designed to help in the tasks. Manipulators, jacks, hoists, derricks, industrial trucks, cranes, backhoes, conveyors, rigging, escalators, elevators, and other equipment are part of the materials handling arsenal. There are many kinds of objects and materials to handle, each posing different hazards. There may be individual objects or groups of objects in boxes, bins, totes, or on pallets. There are buckets and scoops of various types to handle bulk materials, like grain, gravel, earth, and loose parts.

Materials handling is one of the leading causes of disabling occupational injuries. Data about materials handling come from statistics on injury type and industry. Materials handling has a low death rate, but a high disability rate. An overall estimate is that about 20–25% of disabling occupational injuries involve materials handling. For example, 37% of injuries with days away from work involve sprains, strains, or tears.[1] Most of these result from materials handling activities. These injury types occur more often in industries with materials handling activities, such as construction and warehousing. However, nearly any kind of industry has some materials handling injuries.

This chapter will discuss many of these activities and types of equipment used in them. This chapter also addresses materials storage and certain dangerous activities such as excavation and trenching.

Hazards

There are many kinds of hazards for materials handling activities and equipment. Some are unique to particular activities, equipment, or kinds of materials. For example, manual materials handling poses dangers that are different from the use of cranes or hoists. Electrical powered equipment has electrical hazards, while other energy sources pose other hazards, such as flammability. Mobile equipment hazards differ from hazards for fixed equipment. For example, lifting and moving a coil of steel involves some hazards not encountered when loading grain into a bin. Beside handling hazards, some materials themselves are flammable or toxic.

Environments may contribute to hazards in materials handling. Poor lighting and visibility create hazards. Dusty and contaminated air are breathing hazards. Lack of traffic control, congested pathways, and unorganized storage add hazards. Failure of structural elements, brakes, controls and other components can lead to accidents. Training is also important. Workers must learn how to lift items manually to reduce the chances of injury. Operators must learn how to operate materials handling equipment, to properly plan a safe lift, to understand what can go wrong and how to protect themselves, others, and property. Other participants in materials handling operations must know procedures, such as hand signals, staying out from under and away from elevated loads, and use of proper rigging. It is also important to plan materials handling tasks and work. All participants must know the steps in preparing for and completing a lift.

One major hazard in materials handling is failure of the lifting equipment. Excessive load causes many failures for some lifting conditions. For example, for humans, there are sprains and strains of backs, arms, and legs. A crane boom may buckle. A chain or wire rope that is part of the lifting device may break. Rigging that restrains load may fail. A conveyor support may collapse.

Another hazard type is falling loads. Materials may fall on people and cause injury or they may fall on property and cause damage. A load may shift during movement and tip over. Poorly rigged, restrained, or anchored loads may fall.

Another hazard involves materials in motion. Included are the speed and mass of materials and equipment. Objects in motion may strike something and cause damage or strike a person and cause injury. Someone may operate equipment too fast, tip it over, lose control, or fail to stop it quickly. People may get run over. They may get their hands or bodies caught, crushed, or pinched. For some materials, the rate of flow is important. In a process, materials may pile up or back up at certain points, possibly causing workers to rush and act in an unsafe manner.

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Controls

There are many different controls for preventing materials handling accidents. Suitable controls depend on the kind of activity, the equipment involved and the material. There are also controls for the work environments where materials handling occurs. Good lighting, sufficiently wide aisles, good ventilation, traffic controls, visibility, and uncongested and unobstructed pathways are important. So is keeping lift zones clear of people. Proper maintenance of materials handling equipment is essential.

Eliminate Handling Materials handling takes time, costs money, and increases the likelihood of damage to items handled or injury to those doing the tasks. Analysis of operations may identify ways to eliminate materials handling tasks. By eliminating materials handling steps, there are fewer opportunities for handling hazards. Eliminating handling may make sense from a safety point of view. It may also make good economic sense by reducing the cost of work.

Planning If there is a need for materials handling, there should be a handling plan. Planning should identify and analyze steps for what may go wrong. Handling locations should be clear of hazards. Planning should include selection of correct equipment. There should be procedures for stopping work, correcting issues, and resolving hazards. A plan should anticipate communication needs. Communication may include hand signals, two-way radio or other communication systems. All participants must receive training and understand the lifting plan.

Even a simple, two-person lift requires planning. As a minimum, participants should go over how they will proceed from start to finish. They should discuss what they will do if something starts to go wrong and how they will communicate during the process.

Planning should identify if the process will use equipment. It should identify what equipment to use. Often mechanical handling is preferable to manual handling. Often manual handling costs more and is less efficient than mechanical handling.

Design Materials handling tools, devices, and equipment require proper design. Standards published by the Occupational Safety and Health Administration (OSHA), the Society of Automotive Engineers (SAE), the American National Standards Institute (ANSI), the American Society of Mechanical Engineers (ASME), the British Standards Institute (BSI), the European Union (EU) and others cover a range of materials handling equipment. Some of these organizations also require use of procedures to certify the structural and operational safety of certain materials handling equipment. These organizations also require training and certification for equipment operators.

Design considerations must include structural strength, operational features, control systems, visibility, failure modes, incorporation of safety features, and other factors. Even permanently installed materials handling equipment must have safety features. For example, conveyors that move above workers in a factory must have overhead protection to prevent objects and materials from falling on people. Some materials handling equipment must have access ways and guardrails for maintenance and lubrication tasks. Equipment or operations need exhaust ventilation or sprayers to isolate or control dust. Power equipment may need emergency shutoff controls and guards. Each design requires analysis of uses and use environments. Selection of equipment must match user needs to ensure safe use.

Selection It is important to select the right handling equipment for a job. Specific jobs require particular handling equipment. Certain tasks may need specific features. Whoever makes the selection must know the task, the equipment, and the use environment. As noted above, equipment selection is part of materials handling planning.

Use People must use equipment correctly. They need to be trained. Complex equipment requires detailed training. For example, OSHA requires specific training for forklift operators and training and certification of operators of specific types of cranes.

There are many details to know about for each kind of materials handling equipment. Also, loads on materials handling equipment must not exceed safe load limits. Operators must know how to plan a lift and how to read a load chart. Operators must drive mobile equipment safely. Cranes should stay certain distances from power lines (see Case 12-3).

Training Users of each kind of materials handling equipment need particular knowledge and skill. Training is essential not only for operators, but also for others involved in or near materials handling operations. They must learn which hazards may exist and how to control the hazards.

Equipment operators must develop skill in operating controls. They need to know what may go wrong, how to prevent it, and what action to take should something go wrong. They must develop skill in the procedures and judgments related to planning and executing materials handling tasks. They must know which conditions in the use environment add to the hazards of the materials handling tasks. They must know when stopping the activity is more important than injury, loss of life, and loss of equipment or materials.

Environments There are many different and important use environment factors. Examples are lighting, visibility, weather, terrain, properties of materials (weight, toxicity, flammability, stability, etc.), soil and roadway conditions,

and location of people on or near a site. Those involved should ensure that proper controls are in place before handling tasks start. Should a materials handling activity involve workers who speak different languages, communication means must be in place that work for all.

15-2 MANUAL MATERIALS HANDLING

Manual materials handling accidents result in a variety of injuries. Few involve fatalities. Objects and loads may fall and injure hands, feet, and legs. Lifting may cause muscle strains and joint injuries. By far, back injuries are the most common injuries from manual materials handling. According to several studies, low back injuries account for about one-quarter of all workers' compensation claims.

Back claims and complaints are widespread among people and occupations. They often occur in industrial or construction activities. They are common among hospital employees, often resulting from patient lifting and handling. Even office workers report back complaints quite frequently. Results of one national survey estimated that over half of all office workers have back complaints at some time. Another study notes that four out of every five Americans will suffer at least one episode of lower back pain between the ages of 20 and 60.

Hazards

Many things contribute to manual materials handling injuries. Common factors are materials handling techniques, job design, and physical condition and characteristics of individuals.

A biomechanical analysis of lifting gives an insight into some of the problems. When a person lifts and carries an object, the back muscles must counteract the load. Normally, people carry things in front of them. The spine is the fulcrum (see Figure 15-1). The back muscles are a short distance from the spine. The load in front of the body is much farther from the spine. At minimum the distance is greater than the thickness of the trunk. The farther a load is in front of the body, the greater the moment created by the load. Recall from Chapter 10 that a moment is the force (weight of a load) times the distance from a support point. The closer a load is to the body, the smaller the moment, whether standing, sitting, or stooping. The back muscles must counteract the moment created by the load in front. Stooping to raise a load creates even greater moments because an object is farther in front of the feet and body. To keep the moment as small as possible, a load must be close to the body.

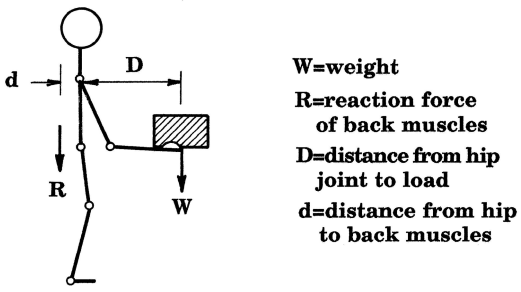


Figure 15-1. Biomechanics of manual lifting. The moment ($W \times D$) created by the load being lifted must be counteracted by the muscles of the back ($R \times d$).

There are some gender differences for lifting. For example, typically the torso length of women is slightly longer relative to body height than men. As a result, most woman will experience a greater moment for a lifting task than will a man of equal height. Because of variability in body dimensions, this generalization does not apply in every case.

The size of a load can contribute to the moment. Someone cannot hold a large object as close to the body as a small object. Depending on its distance away from the body, a large, but relatively light object may produce a greater moment than a small heavy object.

The inertia involved in lifting something can add to the static load. The faster someone raises an object during a lift, the greater the inertial component and resulting moment to overcome. Lifting objects slowly will minimize inertia. Reaching while picking up an object or putting it down will produce larger moments.

The length of a lift (vertical distance) can increase the potential for injury. Lifting something above the shoulders or overhead involves other muscle groups that may have less capacity than the back muscles. For example, a service person who must raise a ladder to the very top of a van is likely to have difficulty. Some service companies have a lever connected to a bracket that lowers a ladder to the side of the van for easy removal. When finished, a worker does not have to raise the ladder to the top of the van, but merely to the hanger positioned on the side of the van. Then the service worker operates the lever that moves the ladder to a secure position on top of the van.

The weight of a lifted object is also important. One study of 550 workers over a two-year period found that few injuries resulted for tasks involving loads less than 45 lb. The weight of items needing lifting is important. Sometimes a simple solution is to change the packaging size to reduce the weight of contents. One may offer products in smaller bags or boxes to make them lighter.

Handholds are important to reduce lifting injuries. Boxes with cutouts for fingers make handling the boxes easier and more secure. Plastic bags for bulk materials with handles or cutouts for hands simplify lifting and carrying.

Frequency of lift is also important. Continuous lifting activity may exceed the physical work capacity of an individual and lead to fatigue, error, and injury.

Rotation and twisting, common in shoveling, racking, and lifting with turning, contribute to materials handling injuries. One-handed lifting is also an important consideration. Because the body is not well suited to asymmetrical loads or rotation, lifting with one hand or twisting during a lift adds to the likelihood of injury.

People vary in size, weight, strength, and physical condition. Physical condition includes general physical fitness, strength and conditioning of muscles, condition of joints, and other factors. Back muscles reacting to a lifted load compress the vertebrae of the spine. The intervertebral tissues have limits. Some studies have estimated the compressive load limits of spinal elements, but the capacity for an individual and particular spinal locations will vary. It is difficult to predict where and under what conditions an individual will experience pain, strain a muscle or experience some other form of injury.

Controls

The National Institute for Occupational Safety and Health (NIOSH) studied many of the factors just discussed. It developed an organized way to estimate the risks associated with various lifting activities. Later the agency updated its method in a guide called the *Application Manual for the Revised NIOSH Lifting Equation*.[2] The guide reviews epidemiological, biomechanical, physiological, and psychophysical literature and recommends controls for minimizing lifting injuries. NIOSH also offers guidelines for manual materials handling.[3] NIOSH defines two groups of controls: administrative controls and engineering controls.

Liberty Mutual Research Center studies identified the loads that men and women can lift safely.[4] They produced data tables based on a wide range of population percentiles. The data address a range of lifting, lowering, pushing, and pulling tasks.

The International Labour Organization has recommended weight limits for manually transported loads by gender and age.[5] For adult male workers the recommended maximum permissible weight is 55 kg (121 lb). For adult women the recommendation is "substantially less than permitted for males." The minimum recommended age for sustained manual transport of loads is 18 years.

Administrative Controls Administrative controls include selection and training of workers. Selection includes physical assessment, strength testing, testing for aerobic work capacity, and job rotation. Training involves recognition of dangers in manual materials handling, how to avoid unnecessary stress, and identifying what a person can handle safely. Various sources list recommended lifting practices. One example is that offered by the National Safety Council.[6] There are also recommendations for particular jobs. NIOSH offers recommendations for patient handling,[7] including training of nurses.[8] Patient handling systems can reduce risks.

Engineering Controls Engineering controls involve risk analysis of jobs and redesign of work and equipment. Some divide engineering controls into three groups. One group covers mechanical, visual, and thermal environments. Another considers alternatives for materials handling systems. The third addresses potential safety and ergonomic problems.

The mechanical environment includes unit size of load, container design, handle and handhold designs, and floor-worker interfaces. The visual environment refers to lighting, color, and labeling. Materials handling system alternatives involve materials handling equipment and job aids, such as hooks, bars, rollers, and other devices. Other chapters provide further discussion about many environmental controls and ergonomic considerations.

The NIOSH Revised Lifting Equation

NIOSH researchers developed an analytical procedure for evaluating the risks associated with various lifting tasks. The method applies to repeated, two-handed lifting tasks for an 8-hour day without increased risk of developing lower back pain (LBP). Based on additional findings, the Revised Lifting Equation (see note 2) updated the initial method published in 1981. The method has limits and does not apply to the following:

- one-handed lifting tasks
- tasks longer than 8 hours
- lifting from seated or kneeling positions
- tasks in a restricted work space
- lifting unstable objects
- lifting while carrying, pushing, or pulling
- lifting with wheelbarrows or shovels
- high-speed lifting movements
- lifting while on slippery surfaces
- lifting in elevated temperature and humidity conditions.

The method produces the Recommended Weight Limit (RWL) from details about a lifting task under evaluation. RWL helps guide the design of a new manual lifting task or the redesign of an existing task. The method also uses the Lifting Index (LI) to estimate the relative degree of physical stress for a lifting task. LI also provides a way to compare and rank manual lifting tasks when setting improvement strategies or prioritizing improvement efforts.

The formula for calculating an RWL involves six multipliers. Each multiplier involves a variable. The recommended procedure is to measure variables at the starting

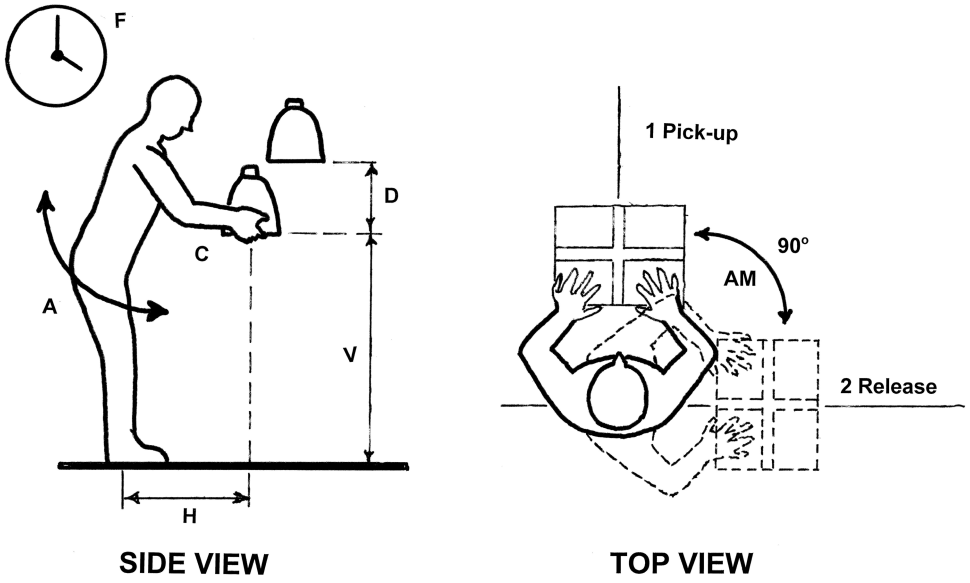


Figure 15-2. Illustration of dimension involved in a lifting task and then used in calculating the Recommended Weight Limit (RWL).

position (origin) of a lift task and at the completion position (destination). Computing RWL at both the start and finish can determine which position has the highest stress based on the Lifting Index. Refer to Figures 15-2a and 15-2b for information on the variables. Consult the publication for additional details when implementing the procedure for various kinds of lifting tasks.

$$\text{RWL} = \text{LC} \times \text{HM} \times \text{VM}\% \times \text{DM} \times \text{AM} \times \text{FM} \times \text{CM} \tag{15-1}$$

where

LC = Load Constant (51 lb)
HM = Horizontal Multiplier
VM = Vertical Multiplier
DM = Distance Multiplier
AM = Asymmetric Multiplier
FM = Frequency Multiplier
CM = Coupling Multiplier

$$\text{HM} = 10/H \tag{15-1a}$$

where H = distance, in inches, from ankles to hand grasps or load center. Instead of computing HM, one can select HM from Table 15-1.

$$\text{VM} = 1 - (0.0075|V - 30|) \tag{15-1b}$$

where V = vertical height of hands above the floor in inches with the normal hand position at 30 in. and the maximum lift height at 70 in. The equation uses the absolute value of V since some tasks raise objects above the normal hand position and others lower objects below the normal hand position. One can select VM from Table 15-2.

$$\text{DM} = 0.82 + (1.8/D) \tag{15-1c}$$

where D is the vertical travel distance in inches of the hands between the origin and destination of the lift. One can select DM from Table 15-3 instead of calculating the value.

$$\text{AM} = 1 - (0.0032A) \tag{15-1d}$$

TABLE 15-1 Horizontal Multiplier (HM) Values for NIOSH Revised Lifting Equation

H, in	HM
≤ 10	1.0
11	0.91
12	0.83
13	0.77
14	0.71
15	0.67
16	0.63
17	0.59
18	0.56
19	0.53
20	0.50
21	0.48
22	0.46
23	0.44
24	0.42
25	0.40
>25	0.00

TABLE 15-2 Vertical Multiplier (VM) Values for NIOSH Revised Lifting Equation

V, in	VM
0	0.78
5	0.81
10	0.85
15	0.89
20	0.93
25	0.96
30	1.0
35	0.96
40	0.93
45	0.89
50	0.85
55	0.81
60	0.78
65	0.74
70	0.70
>70	0.00

where *A* is the asymmetry angle, the angle between the mid-sagittal line of the body and the asymmetry line (the angle turned without pivoting or stepping). One can select AM from Table 15-4.

One must determine FM from Table 15-5. This table involves a variable, F, which is the number of lifts per minute (frequency). The table also accounts for the overall time someone continues the lifting task and the vertical height, *V*. FM ranges from 0.0 to 1.0. One can select FM from Table 15-5.

To apply the CM, one must determine how someone grips the lifted materials. Table 15-6 provides classifications for good, fair, and poor hand-to-container couplings.

TABLE 15-3 Distance Multiplier (DM) Values for NIOSH Revised Lifting Equation

D, in	DM
≤ 10	1.00
15	0.94
20	0.91
25	0.89
30	0.88
35	0.87
40	0.86
45	0.86
50	0.85
55	0.85
60	0.85
70	0.85
>70	0.00

TABLE 15-4 Asymmetry Multiplier (AM) Values for NIOSH Revised Lifting Equation

A, degrees	AM
0	1.00
15	0.95
30	0.90
45	0.86
60	0.81
75	0.76
90	0.71
105	0.66
120	0.62
135	0.57
>135	0.00

Table 15-7 lists the CM based on coupling classifications and vertical height, *V*. One can select the coupling classification from Table 15-6 and CM from Table 15-7.

Applications

In order to evaluate a simple lifting task with the Revised NIOSH Equation, one must collect the data describing the lift. Needed are the weight of the object, horizontal, and vertical locations, the angle of asymmetry, lift frequency, total duration of the task, and coupling classification. Then one can compute RWL and LI. It is good practice to repeat the process for both origin and destination positions to see which has the greater stress. Figure 15-3 provides a worksheet for data collection and task analysis.

From the results, one can determine if there are potential administrative or engineering changes to the task. If there are changes, one can revise the data and recompute the RWL and LI to see if changes reduce the lifting stress. There may be several options for changes. The process allows for comparing each option to determine which may be best.

If there is a multi-task procedure, such as unloading or loading a pallet or changing lift frequencies, the publication provides additional instructions for analyzing such complexities.

Example 15-1 A worker parks a hand truck near a mixing hopper. The worker will stand between the hand truck and the hopper. The task is to lift each of the eight bags from the hand truck and place the bag on the rim of the hopper to open it and let the contents spill into the hopper. During the lift, the worker twists from the hand truck position to the hopper position. The task occurs roughly 10 times per 8-hour shift. The most difficult bag to lift is the bottom one. It justifies analysis first. Compute the RWL and LI for the task and recommend any revision to the lifting task.

TABLE 15-5 Frequency Multiplier (FM) Values for NIOSH Revised Lifting Equation

	Work Duration					
	≤ 1 hour		> 1 but ≤ 2 hours		> 2 but ≤ 8 hours	
F[a] Frequency Lifts/min	V, in < 30	≥ 30	V, in < 30	≥ 30	V, in < 30	≥ 30
≤ 0.2	1.0	1.0	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

[a]For lifting less frequently than once per 5 minutes, set F = 0.2 lifts/min.

Data for the lifting task are the following:

- The hands are at a vertical location of 15 in. for the origin and 36 in. at the destination.
- The hands are at a horizontal location of 18 in. at the origin and 10 in. at the destination.
- The asymmetric angle is 45 degrees to the left from the origin to the destination.
- The frequency is fewer than 0.2 lifts/min. for less than 1 hour.
- The worker can flex the fingers approximately 90 degrees. The bags are fairly rigid and do not sag in the middle.
- Each bag weighs 40 lb.

From the data, the following multipliers result:

$$LC = 51$$
$$HM = 10/H = 0.56$$
$$VM = 1 - (0.0075|V - 30|) = (0.0075|15 - 30|)$$
$$= 1 - 0.11 = 0.89$$
$$DM = 0.82 + (1.8/D) = 0.82 + 1.8/21 = 0.91$$
$$AM = 1 - (0.0032A) = 1 - (0.0032[45]) = 1 - 0.14 = 0.86$$
$$FM = 1.0 \text{ from Table 15-5}$$
$$CM = 0.95 \text{(from Table 15-7), because the coupling classification from Table 15-6 is "fair" for } V < 30 \text{ in.}$$

Then RWL = 18.9 lb and LI = 40/18.9 = 2.1

Possibilities for improving the task are bringing the load closer to increase HM, reducing the asymmetry and increasing AM by repositioning the hand truck relative to the

TABLE 15-6 Coupling Classifications for Use in Table 15-7 [a]

Good	Fair	Poor
For optimal design containers, such as boxes, crates, etc., with handles or hand-hold cutouts of optimum design.	For optimal design containers with handles or hand-hold cutouts with less than optimal design	Less than optimal design containers, loose parts, or irregular objects that are bulky, hard to handle, or have sharp edges
For loose parts or irregular objects which are not usually containerized, such as castings, stock, and supply materials that are comfortable to grip, so hands easily wrap around the object.	For optimal design containers without handles or hand-hold cut-outs or for loose parts or irregular objects that allow the hand to flex about 90 degrees.	For lifting non-rigid bags that sag in the middle.

[a]Refer to the full report for additional detailed descriptions of hand-to-container couplings.

TABLE 15-7 Coupling Multiplier (CM) Values for NIOSH Revised Lifting Equation

Coupling	Coupling Multiplier (CM)	
Classification	V < 30 in	V ≥ 30 in
Good	1.0	1.0
Fair	0.95	1.00
Poor	0.90	0.90

hopper, and raising the height of the bags at the origin to increase VM. For example, by decreasing H to 10 in., RWL would increase to nearly 34 lb and LI would decrease to approximately 1.2.

15-3 JACKS

There are many kinds of jacks including hydraulic, mechanical, and pneumatic ones. There are bumper jacks for older cars, scissors jacks, jacks with ratchet mechanisms, and jack screws. Each jack has a maximum design load. Although jacks are very common, users should understand how to use them safely and what their load limits are before using them.

Hazards

A major hazard with jacks is overloading their capacity or that of other items used with a jack during a lift. A failure may let the load fall suddenly and crush someone or cause damage. Another hazard is improper placement. A jack must be set on a solid base. A poor base may cause tipping or slipping. Because a jack is a single point support and relies on a good contact at the base and at the point of lift, it can tip or slip, causing the load to fall. As a single point support, a jack can be unstable. Lateral forces may cause it to tip and fail.

A jack may have enough capacity to support a load, but the surface or structure that it sets on or bears against may not have enough capacity. For example, a jack placed on the ground may sink when fully loaded. A lifted object may not withstand the load and fail by bending, breaking or puncture.

Because they only support a single point, jacks are rather unstable. The instability may increase due to a small bearing support area for a jack or increased lift height. Because of their instability, loaded jacks may tip easily. If not properly positioned, they may slip at the top or the base. The object being lifted may shift and make the jack tip.

Most jacks are made of steel. Most lift steel objects. The coefficient of friction for steel against steel is very low and a small lateral load may cause a load to slip.

JOB ANALYSIS WORKSHEET
Single Task - NIOSH Revised Lifting Equations

Department	**Description of Job**
Job Title	
Analyst / **Date**	

Step 1. Measure and record task variables

Object Weight (lb)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Freq Rate	Duration	Object Coupling
		Origin		Destination			Origin	Destin.	lifts/min		
L (Avg)	L (Max)	H	V	H	V	D	A	A	F	Hrs	C

Step 2. Determine the mulitpliers and compute the RWL's
RWL = LC x HM x VM x DM x AM x FM x CM

Multiplier	LC	HM	VM	DM	AM	FM	CM	RWL
ORIGIN								
DESTINATION								

Step 3. Compute the Lifting Index (LI)
LI = Object Weight (lb) / RWL

ORIGIN	Object Weight =	RWL =	LI =
DESTINATION	Object Weight =	RWL =	LI =

Figure 15-3. Job Analysis Worksheet for the Revised NIOSH lifting equations.

Controls

A jack should have enough capacity for the lifted load and should have a solid bearing support to prevent sinking or slipping. Jacks should be plumb throughout their use. Sometimes jacks or jack-type devices pry things apart. In such cases, position them so that the ends are well anchored and will not slip. Stabilizing and blocking a load at several locations will prevent a jack from tipping or slipping. It is good practice to block or anchor a load.

Avoid metal on metal when using a jack. A wooden block placed between the jack and the load can reduce the chances of slipping because it will deform at compression points and help keep the jack and load aligned.

People should stay clear of a raised load until blocked and anchored so it cannot move. A jack alone should not support a load. After raising an object with a jack, blocking or other supports should hold the object in the elevated position. Blocks must be substantial. An example of a poor blocking material is a concrete block. Because of its brittleness and tendency to crack, it is not substantial enough to support a vehicle when someone underneath makes repairs. The concrete block can crack and fail unexpectedly causing the vehicle to fall.

15-4 HAND-OPERATED MATERIALS HANDLING VEHICLES

There are many kinds of hand-operated materials handling vehicles. Hand trucks, dollies, carts, and wheelbarrows are hand-powered. There are also hand-operated vehicles that use batteries or other power sources. An example is a walk-behind, powered pallet dolly.

Hazards

Like all other load-carrying devices, one hazard is a load shifting or tipping and falling. When maneuvering hand-powered vehicles in tight spaces, an operator may strike the handles against a wall or objects and injure the hands. A hand-operated vehicle loaded too high will obscure the view of an operator and may cause accidents.

A variety of traffic problems can occur for vehicles in motion. Examples are blind corners and vehicles moving in different directions. When pulling a load, an operator may slip or fall. An operator's foot may slide under the vehicle. In addition, the momentum of the vehicle and load may cause the vehicle to run over the operator. When pushing a load, an operator may have difficulty seeing obstructions or maneuvering the load accurately. However, when pushing a load, the vehicle is not likely to run over the operator if there is a slip or fall.

An example is a hospital crash cart loaded with oxygen tanks, medicines, and other emergency supplies. Such carts may weight 200–300 lb. Hospital staff rush a loaded cart to a patient room to treat emergency, life-threatening conditions. Because of the weight and the difficulty of maneuvering the cart around turns in a corridor, two people often rush it to an emergency site. One person pushes and one pulls. In one case, such a cart ran over the heel of the person pulling on it and severed an Achilles tendon.

Controls

Loads should be stable and well secured. Loads should have height limits to provide good visibility for an operator. Loads should not exceed weights that exceed a vehicle's capacity or create handling difficulty for an operator. In most cases, it is preferable to push a load rather than pull it. If a hand-operated, powered vehicle can raise a load overhead, the vehicle should have overhead protection for the operator. That will prevent any falling materials from striking the operator. Such a vehicle may also need outrigger devices to assure stability.

For a pulled vehicle, the tongue and handle should extend far enough from the vehicle so it will not run over an operator's feet. Powered hand-operated vehicles should move at speeds that allow an operator to maneuver and stop them easily. Design features, like large diameter wheels or pneumatic tires, can make maneuvering and operation easier on rough surfaces and over bumps. Handles should have recessed locations or shields for hands to protect them from crushing. There are knuckleguards for some hand trucks to provide hand protection. Incorporating soft rubber bumpers on the handles or other protruding elements of a cart can reduce injury and damage if a cart runs into something.

Some hand-operated vehicles have designs for particular handling tasks, for example, hand trucks for handling gas cylinders. They have restraints that fit around a carried cylinder. The operator must anchor the restraints to prevent the cylinders from falling and creating additional hazards. There are special carts for handling carboys of acids or cryogenic liquids. Operators must learn to secure the containers.

15-5 POWERED VEHICLES

Equipment

There are many different powered vehicles for materials handling. The term industrial truck covers many of them. The most common industrial truck is a forklift truck, fitted with two forks or tines. Some have other devices beside forks for special lifting tasks. For example, some have a single, long fork for lifting carpet rolls and similar rolled material. Some have a clamp device to pick up rolls of paper that normally rest on the end of a roll.

Some industrial trucks pull carts or push objects. One can see some of these vehicles, called tugs or tractors, in use at an airline terminal (refer to Case 15-1). There are backhoes,

CASE 15-1

February 21, 2014, Los Angeles, CA. A 51-year-old ramp agent employed by Menzies Aviation drove a tow tractor to pick up cargo. At some point the worker was thrown from his vehicle. Co-workers found his head pinned underneath one of the tires. The worker died.

An inspection following the accident established that the tractor had only a portion of a seatbelt. It appeared that the worker did not buckle it because of the incomplete belt.

Cal/OSHA issued a $77,250 fine. OSHA observations identified that the employer did not require drivers of tow tractors to use seatbelts and even discouraged their use.[a]

[a]www.dir.ca.gov/DIRNews/2014/2014-74.pdf

end loaders, scrapers, bulldozers, earthmovers, and other powered vehicles for handling soil and bulk materials.

Hazards

Powered materials handling vehicles have some hazards in common. Included are many of the hazards discussed for motor vehicles in Chapter 14. Other hazards are unique to particular vehicles and their use. There are also hazards related to the kind of power.

All powered materials handling vehicles may have visibility problems for an operator, although the problems may differ in type and degree. Operators may have trouble seeing over a load or behind a vehicle. Operators can drive vehicles over someone or something or back over them. The operator may not be able to see all of a load or its overall condition.

All powered vehicles have hazards related to traffic and the movement of several vehicles in the same area. There are minimum space requirements for safe operation and all have hazards related to proper design and functioning of controls, lifting devices, brakes, and steering. A failure of these components could lead to accidents. Vehicles have load limits, and exceeding safe load limits can lead to structural failure and accidents. There are hazards related to proper loading and load stability. A falling load could injure the operator, someone nearby or could damage the vehicle, materials, or objects nearby.

All powered materials handling vehicles have hazards associated with improper operation and use. For example, driving with a load in an elevated position may result in striking an overhead, protruding object or door header. It may lead to tipping while going around a corner.

There are hazards associated with the sources of power. Most battery-powered vehicles use lead-acid batteries, which face the dangers related to electricity and to battery charging. Gasoline and propane fuels, used to power some vehicles, are flammable. Engines and exhaust are hot. In poorly ventilated or confined spaces, battery charging can elevate hydrogen to explosive levels. Engine exhausts could create dangerous levels of carbon monoxide.

Many powered materials handling vehicles have a high center of gravity. When operated too fast in a turn, they can roll over. The problem is even greater when there is an elevated load during a turn. Because the load on a forklift or similar vehicle sits cantilevered in front of the vehicle, counterweights help reduce the chance of a loaded vehicle tipping over.

One can analyze the potential for rollover in a turn by evaluating moments about the lateral boundary of support formed by the tires along their outer edges (lateral support line). The procedure compares the centrifugal force to the pull of gravity about the lateral support line. From this analysis, the maximum forward or rearward velocity V_{max} a vehicle can handle in a turn without tipping over is

$$V_{max} = [gr(d_{cg}/2h_{cg})]^{1/2} \qquad (15\text{-}3)$$

where

V_{max} is in feet per second
g = gravitational constant (32.2 ft/s^2)
r = turn radius (feet)
d = distance from the composite center of gravity for the vehicle and load to the lateral support line (feet)
h = height of the composite center of gravity from the ground (feet)

Example 15-2 (a) A loaded, four-wheeled cart weighs 500 lb. The wheels on each axle are 24 in. apart and the axles are 48 in. apart. Its center of gravity is at the center of the cart in plan view and 30 in. from the floor in side view. An operator pulls the cart around a corner. The turning radius is 6 ft. What is the maximum velocity for the cart that will not cause it to tip over? Applying Equation 15-3,

$$V_{max} = [32.2(6)\{(12/12)/2(30/12)\}]^{1/2}$$
$$= 6.22 \text{ ft/s} = 4.24 \text{ mi/hr}$$

(b) If the center of gravity were 36 in. high and the turning radius 10 ft, what is the maximum velocity without tipping over?

$$V_{max} = 7.33 \text{ ft/s} = 4.99 \text{ mi/hr}$$

A vehicle may skid in a turn. One can calculate this potential by comparing the force acting horizontally on the

vehicle and the frictional force on the tires. The horizontal force is the centrifugal force at V_{max}. If it is greater than the resistance force of friction, the vehicle will skid before it will tip.

Example 15-3 Consider the vehicle in Example 15-2(a). Assume the coefficient of friction μ between wheels and the floor is 0.65. Will the vehicle skid before it will tip?

Assuming all wheels are in contact with the supporting surface,

The frictional force acting at the wheels is $F_f = \mu N$.
The centrifugal force $F_c = mV^2/r$.
The centrifugal force $F_c = (500/32.2)(4.99)^2/6 = 64.4$ lb
The frictional force $F_f = 0.65(500) = 325$ lb
Because $F_f > F_c$, the cart will not skid, but may tip.

Operating materials handling vehicles on rough, irregular, and sloping surfaces can add to instability. The momentum of a jostled and tilted vehicle and load could cause the load to fall or the vehicle to tip. A load or vehicle may tip, even on a smooth, sloped surface. If the sum of forces acting through the center of gravity falls outside the support zone created by the tires, the vehicle will tip over. An analysis of static conditions will reveal when forward, rearward or lateral tilt will cause tipping for various load elevations. Dynamic conditions are more difficult to analyze.

Some vehicles, like forklifts, can raise a load overhead. A load or parts of it that fall from an elevated level can injure the operator or anyone nearby.

Another hazard for some vehicles is catching on protruding objects during operation. For example, forklifts often carry loads into or out of truck trailers. Some rollup doors on truck trailers have short, flat straps for pulling a door down. A short loop of flat, stiff material is not likely to catch on the frame of a forklift or its load. However, if the door pull is merely a piece of round rope, the rope may catch in a pinch point on the mast of the forklift. If there is a knot in the rope, the likelihood of catching increases. If the door pull catches, it can pull the trailer door onto the load or forklift operator.

Obstructions, like items protruding from storage racks, door frames, and suspended light fixtures, can extend into the potential operating zone of a materials handling vehicle and create catch points or introduce other hazards.

Controls

To protect operators from vehicle rollover injuries, some vehicles have a rollover protection system (ROPS). The concept is the same as that for motor vehicles. The goal is to create a protected compartment surrounding the operator. During an accident it is essential to retain the integrity of the operator compartment. For some vehicles a rollover bar is the ROPS. Other elements of the vehicle structure help establish the envelope for the compartment. For other vehicles four columns and connecting crossbars or a cab that meets ROPS standards create the safety envelope for the operator. During a rollover, seat belts prevent the operator from being thrown from the compartment or crushed by ROPS or the vehicle itself.

One study estimated that 80% of operators of farm tractors who were killed in rollover accidents had vehicles without ROPS. With ROPS, the fatality rate was very low.

Operators need overhead protection from falling objects. Materials handling vehicles that have this hazard need a falling object protection system (FOPS). The size of opening should be small enough to prevent objects that are part of a load from penetrating into the operator compartment. The FOPS design must allow an operator to see the load through or around the FOPS. If there is a hazard from materials falling onto an operator when a vehicle backs into something, FOPS should extend to the rear of the operator. Protective systems often combine ROPS and FOPS. The Society of Automotive Engineers (SAE) has several ROPS and FOPS standards. OSHA incorporates many of these standards into its regulations.

The integrity of the operator compartment provides protection from other hazards as well. For example, the operator stands in some industrial trucks. If feet or other parts of the body can extend outside the vehicle, they can be crushed if the vehicle runs into something or passes close to an object, wall or column. Protective enclosures or doors can reduce this hazard.

To help prevent vehicles from backing over someone, the vehicle should have audio and visual warning devices. They warn others that a vehicle is moving backward or in a direction where the operator cannot see well.

Proper maintenance of vehicles and their components will help ensure safe use. When trailers or towed containers undergo loading, trailers must have restraints. Examples are, wheel chocks, devices to lock trailers to loading docks or other devices that prevent trailers from moving during loading or unloading. A common failure is a forklift falling between a dock and a trailer when the trailer rolls forward.

Facilities may need controls for hazards. For example, areas with vehicle exhaust may need ventilation. For some locations, electric vehicles may offer a safer choice.

Other controls for facility hazards include keeping areas clear of obstructions where materials handling vehicles operate. Also important is having horizontal and vertical pathways large enough for a safe maneuver of a vehicle and its load. There is a need to provide protective barriers for racks and other objects, which could pose dangers when struck by powered vehicles that operate nearby.

Where visibility is a problem, visual assistance will prevent accidents. The assistance may be a mirror in the facility or on the vehicle. A classic products liability case involved the lack of a rear view mirror on a materials

handling vehicle. Having a coworker use standard hand signals is another form of assistance.

Operators must have training in safe use of a vehicle. In most cases operators have primary responsibility for safe materials handling operations for their vehicles, so they must learn to recognize hazards of the vehicle and its operations. Knowing and anticipating what might go wrong and taking the right action will help prevent materials handling vehicle accidents.

15-6 HOISTING APPARATUS

Equipment

There are many kinds of equipment for hoisting and positioning materials. Not all are discussed here. Most involve vertical movement of materials. Some include lateral movement or a combination of motions. There are hand-operated and powered hoists; block and tackle devices, derricks and winches of various types; fixed and mobile cranes, tower cranes, gantry cranes, overhead cranes, and boom cranes. There are aerial baskets for positioning people and elevated baskets for positioning supplies and not for use by people. These devices may be independent or permanently installed in buildings. Some are mobile, mounted on trucks or railroad cars. Most hoisting equipment involves rigging of some kind. Some equipment may have special features and fixtures for handling particular kinds of materials or objects.

Hazards

Hoisting devices have some of the same hazards as other materials handling equipment. Elevated materials can fall on people or items below. Structural failure can occur when loads exceed equipment capacity. Hoisting equipment may become unstable and tip over under certain loading or environmental conditions. Equipment or load failures are likely to cause damage, injury, or death. Operators may have limited visibility and need help to lift and position loads.

Equipment must have effective support for wheels, outriggers, or other kinds of supports to carry a load and not tip over. Operations near power lines can result in arcing and electrocution (refer to Case 13-3). Operations in windy conditions may cause overloads and structural failure (see Case 15-2).

There are also hazards associated with the kind of power, the type of operation, the handled materials, and the condition of the vehicle and its components.

Controls

One control for hoisting apparatus is proper setup. This can include placement on a level site, staying away from power lines and proper assembly of tower, boom, jib, and other elements. Chains and ropes must be free of kinks and twists. Hoisting equipment requires regular inspections, preferably before startup each day or before use. Several organizations publish standards for hoisting equipment.[9] Regulations require periodic certification for use for some hoisting devices. There is a need to check whether soil conditions and other factors are suitable. For some crane operations, there is a written lift diagram or plan requiring approval by all participating parties. During setup and periodically, a crane needs inspection for stability. Different cranes use different means for achieving stability. Mobile cranes may need outriggers. Tower cranes need anchoring cables and proper counterweights.

Another control is lift planning. That helps ensure a safe load and lift. In some cases, there is a need to complete precise load calculations that account for many factors. Hoisting apparatus should have load limits clearly marked. The ratings assume a static load. Jerked loads or loads dropped some distance create dynamic conditions. They place inertial loads on the rigging and structure and may overload them. Cranes, for example, should have a load chart affixed to the operator's cab and an operator's manual in the cab. The operator must know the weight of the load. That and other information allow the operator to use the load chart and ensure the capacity of the equipment is not exceeded.

The operator must be trained. Many kinds of hoisting equipment require testing and certification of operators. An example is the testing and certifications offered by the National Commission for Certification of Crane Operators.[10]

Some hoisting equipment has simple controls whereas other types have complex controls. The operator must know more than how to make the crane and its movements work. The operator must know what can go wrong and how to prevent such events. An operator must anticipate dangerous situations, monitor changing conditions and ensure safe operations. An operator must know about rigging and assure that loads have proper rigging.

Operating hoisting equipment safely can be a very complex process. For example, to make a safe lift with a mobile crane, an operator must have at least eight items of information:

1. Is the vehicle level?
2. Are all outriggers extended or retracted?
3. Are extended outriggers supported by stable ground?
4. Are tires fully inflated?
5. What is the angle of the boom?
6. What is the boom and jib length?
7. What positions will the boom be in during the lift?
8. How much does the load weigh?

RATED LIFTING CAPACITIES IN POUNDS
BOOM LENGTH : 29-95 ft
OUTRIGGERS 50% EXTENDED FOR 360° OPERATION

Radius in Feet	Main Boom Length in Feet							
	29	40	50	60	70	80	90	95
10	60,000	48,000	45,000					
12	53,300	48,000	44,950	37,000				
15	42,100	40,500	38,350	36,000	27,400	21,000		
20	23,950	23,850	23,900	24,050	23,200	21,000	17,000	15,500
25		15,850	15,950	16,150	16,350	16,400	15.950	15,300
30		11,350	11,500	11,800	11,800	12,000	12,150	12,100
35			8,620	8,930	8,930	9,050	9,190	9,260
40			6,610	6,900	6,900	6,990	7,100	7,150
45				5,400	5,400	5,470	5,550	5,600
50				4,260	4,260	4,310	4,370	4,410
55				3,350	3,350	3,390	3,430	3,460
60				2,600	2,600	2,640	2,670	2,700
65						2,020	2m050	2,060
70						1,490	1,520	1,530
75							1,070	1,080

Notes:

1. Bold horizontal line across cells indicates structural failure risk above the line and tip-over risk below the line.
2. Chart is intended to illustrate load chart complexities, but is greatly simplified from actual charts.

Figure 15-4. Illustrative example of a mobile crane load chart. The illustration covers only a few of the conditions important in deciding whether it is possible to make a safe lift.

If the operator knows all of these, the operator can make readings on the load chart unique to the crane model and can determine if the operation will be within all structural and stability limits. See Figure 15-4 for an abbreviated example of a load chart for a mobile crane. The limits assume a level machine. There are different limits when tires are not fully inflated and when the outriggers are not in place.

The distances from the pivot point to outrigger or tire support points on the side or ends typically are not the same. The limits differ for a load lifted over the side compared to a load over the front or the rear of the vehicle. Moving a load to different positions may cause structural failure or tipping of a mobile crane. The boom angle and length also affect what load is safe. When cranes operate in tight spaces, there is a need to make precise measurements for making a safe lift.

Typically, a load chart identifies two kinds of failures. Loads appearing above a line through the chart indicate potential structural failure. Loads below the line indicate potential tipping. Excessive wind, potential contact with electrical lines and equipment, job site congestion or poor soil and bearing under outriggers may require terminating a lift operation.

A load must have proper rigging. All participants must understand the lifting plan. The load must fall within the safe limits of the load chart. After all members of a lift team understand the plan, an operator can lift and move a load safely. The team may include observers. Someone may monitor the load to ensure that it remains stable and rigging does not fail. Someone else may monitor the lift zone to make sure others remain clear during a lift. Someone may monitor surrounding conditions or work to prevent any interference with a lift. An assistant may use standard hand signals to guide the operator, who cannot see the load during parts of the operation. One or more workers may operate tag lines connected to the load to keep it stable and help maneuver it through tight places.

There are many design features that can reduce risks in the use of hoisting apparatus. Not all safety features in cranes are fail-safe devices. Each device has limitations. This discussion covers a few examples.

CASE 15-2

July 14, 1999. Milwaukee, WI. A new baseball stadium was under construction for the Milwaukee Brewers Major League Baseball team. The design included a unique, retractable roof. To assemble the large roof panels, the project used the world's tallest crane, which had nearly a 600-foot-high boom. The crane had the nickname "Big Blue." While lifting a 420-ton section into position atop the roof, the crane collapsed, killing three workers. During the lift that day, an anemometer located nearly 200 feet up the boom gave continual wind readings to the crane operator. At times, the wind gusts reached 25–30 mph.

The incident resulted in major cleanup costs, project delays, legal battles, and compensation awards costing millions of dollars. OSHA issued $539,000 in fines to three companies involved in the project. There was some argument whether the wind load was properly included in pre-lift load calculations.[a,b,c,d]

A statue of the three workers stands outside the stadium as a memorial.

[a] www.youtube.com/watch?v=qNPQjid8oJc
[b] www.oshrc.gov/decisions/html_2002/00-0289.html
[c] http://ehstoday.com/news/ehs_imp_32876
[d] http://legis.wisconsin.gov/lab/reports/02-8full.pdf

The structure of an overhead crane is often part of a building's structure. Overhead cranes operate on rails attached to building columns. This allows the crane bridge to move through a building elevated well above the floor. A trolley attached to the bridge of the crane provides movement perpendicular to the movement of the bridge. The rails of the bridge and trolley should have limit switches and bumpers to prevent them from running off the ends of the rails or into the building structure.

Cranes may have built-in safety devices or warning devices. One type of device is a load indicating device (LID). It measures load weight and displays a reading for the operator. It may include an overload warning signal if a load exceeds some predetermined weight.

There are limit switches to prevent "double blocking." Double blocking refers to the load block or hook reaching the top of its travel and trying to or actually passing over a sheave. When double blocking occurs, the hoisting mechanism is likely to become overloaded and fail. Also, the mouth of the hook may reach a position where the end loops of a sling fall out of the mouth. The limit switch warns the operator of these potential dangers.

Boom cranes have special safety devices for their unique hazards. One device is a boom angle indicator or boom radius indicator. A reading from this device provides the operator with information to help determine if a load is within safe limits. There are also devices, called load-moment indicators, that combine boom angle and load. If there is a load with the boom set at a certain angle, the moment may exceed the allowed moment and cause a crane to tip over. The device sounds an alarm for the operator when approaching or exceeding the limit.

When crane booms operate near overhead power lines, there is a danger of contacting them and possibly electrocuting the operator or someone in contact with the crane. There is also a similar danger from arcing in proximity of a power line. There are power line proximity warning devices that notify an operator if the boom gets too close to an energized power line. Regulations require that booms be kept certain distances from such energized power lines. The required safe distance depends on the voltage of the power line. There are also devices for insulating cranes and booms if there is contact with an overhead power line. It is important to ground cranes and other materials handling equipment that could come into contact with electrical power sources.

Some cranes may need an anemometer on the boom. It can provide direct and continual readings of wind speed for the operator. A load plan should identify the wind speeds that limit making lifts.

15-7 ROPES, CHAINS, AND SLINGS

Equipment

Ropes, chains, and slings are the rigging used to lift loads. They form the interface between the hoisting equipment and the load. There are many kinds of rigging materials and devices.

Rope normally have twisted strands of material. There are ropes made from natural fibers like manila. There are ropes made from synthetic fibers like nylon and polypropylene, and there are metal ropes, usually of steel. The nomenclature for wire rope usually includes an outer

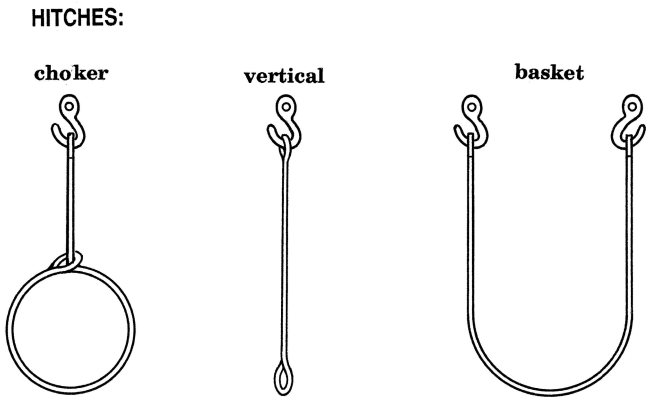
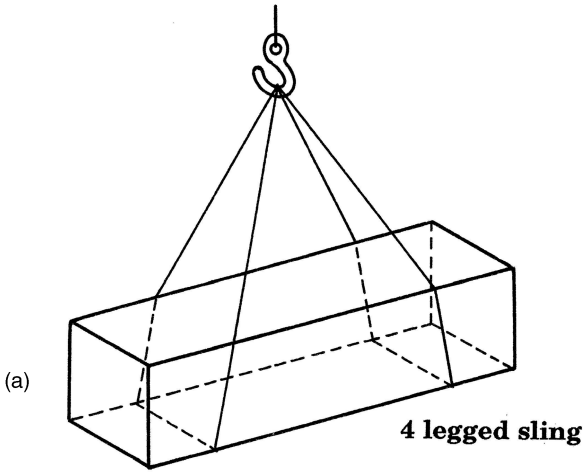


Figure 15-5. Three main types of slings.



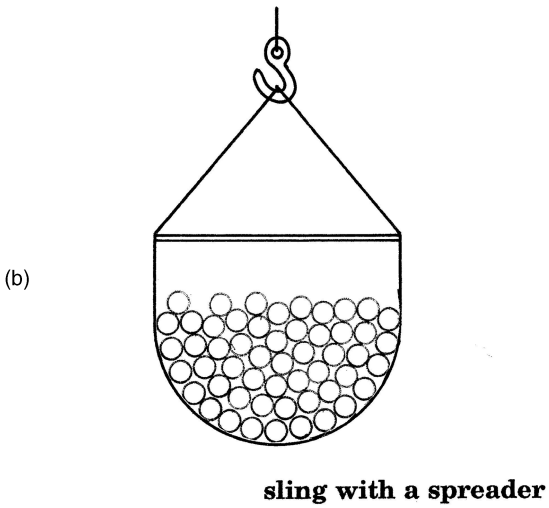


Figure 15-6. (a) A four-legged sling and (b) a sling with a spreader.

diameter. Wire rope also has a numbering system that indicates the number of wire bundles in the rope surrounding the core and the number of continuous wires within each bundle. For example, in a 6×19 wire rope there are six bundles composed of 19 wires each, a total of 114 wires.

A common rigging component is a hook on the end of a rope built into a hoist or crane. Loads hang from the hook. Like other elements of rigging, a hook has a load limit.

Slings support a load and connect to a hook. There are many kinds of slings. Slings normally have a fixed length. Most have no adjustment. Slings are made from various materials. They may have the form of rope, chain, belt, mesh or fabric. To prevent damage to a lifted object, a sling may be a wide band of fabric or a belt to distribute the load. This prevents the sling from cutting into or scratching the object. Some slings have a loop on each end. One or both loops may attach to the mouth of a hook. There are different ways to suspended slings from a hook. Figure 15-5 illustrates three common methods: vertical, choker, and basket hitch. There are several other sling arrangements. Some slings have more than two legs and slings with three and four legs are quite common. Some slings have a hook on the end of each leg instead of a loop.

In some rigging arrangements a spreader placed between legs of a sling above the load helps the sling legs stay vertical rather than compressing around the sides of the load. The compression may damage the lifted material. Figure 15-6(b) illustrates the use of a spreader with a two-legged sling.

Hazards

The main hazards of rigging are failures. The failures may result from overloading, deterioration or wear, and exposures to damaging conditions or materials. Improper rigging or abuse of rigging also can cause failures.

Each type of rigging can carry some defined load. A rope of a certain diameter has a rated capacity based on ultimate strength and a factor of safety. Chapter 10 discussed factors of safety for materials. Various factors reduce the capacity of a rope or its efficiency. Examples are fittings on the rope, the way someone uses a rope, and a rope's physical condition. The reduction in capacity can vary a lot. A rope, chain, or sling is no stronger than its weakest element. A rigging with full capacity has a 100% efficiency rating. Fittings, splices, bends around sheaves or objects, and damaged segments or links can all reduce the load capacity to an efficiency below 100%. Tables and charts in several references give efficiencies for fittings and splices. OSHA publishes guidance and charts of sling capacities.[11]

The load capacity of a sling depends on the type of hitch applied when rigging a load. The type of hitch determines the number of active legs. For a choker hitch, one live element or leg of the sling ends up carrying the entire load (see Figure 15-5). In a vertical hitch, one leg carries the entire load. In a basket hitch, there are two live legs, each carrying half the load if they are vertical.

The load capacity of a sling also depends on the angle formed by the legs. Refer to Figure 15-6 for a four-legged sling. The greater the angle formed between the vertical and a sling's leg, the greater the load on the leg. (Note: some sources list angles measured from horizontal rather than vertical.)

Improper attachment may cause a load to slip out of its rigging. For example, it is not uncommon for a load to slip from a two-legged sling.

Most hooks are ductile steel because it is more durable under repeated loading than more brittle steel. If rigging becomes disengaged from the mouth of a hook, the load will fall. Due to repeated loading, the mouth opening of a hook may stretch and widen. This can increase the chances of rigging slipping from the hook.

Exposure, improper storage, and continued use can reduce rigging capacity. Weather, sunlight, high temperatures, chemicals, moisture, or other elements can damage rigging. Sunlight affects the strength of certain synthetic materials. Moisture can induce rotting in natural materials and corrosion in metals. Rigging gets damaged when run over, dragged around, or loads fall on components. When ropes bend around small radius corners or sheaves, the outer fibers become stressed and may fail. Wear reduces the size of some wires or fibers, thereby reducing their capacity.

Another hazard of rigging is injury to users or others nearby. If rigging fails, a load can fall and possibly injure someone nearby or below it. Loaded rigging stretches and stores some energy, much like a rubber band (some rigging materials stretch more than others). If there is a failure, the line can snap back in each direction from the break. The line, a clevis used for a connection or some other component, may fly rapidly and strike someone. Even a tug-of-war rope is known to have ripped participants' hands and fingers when it breaks. The greater the elongation and energy stored, the greater the danger of injury following a failure.

Controls

Many actions help minimize rigging hazards. Included are the proper selection of rigging materials, proper use, not overloading the rigging, regular inspection and testing of rigging components, training of riggers, and effective presentation of reference materials.

The *Handbook of Rigging* is a long-standing reference on proper selection, use, inspection and testing of rigging. There are several other references on rigging. Several national and international standards define the frequency and method for testing of certain rigging components.

Inspections of rigging are important for safe use. For example, ropes have about 25 kinds of failures to discern. Some failures, like broken outer wires or fibers, are easy to detect. Other failures are difficult to find visually.

Users must inspect hooks for cracks and growth in the jaw opening. It is time to remove a hook from use when the angle of the jaw increases by 15 degrees from its original opening. The main reason is the chances of rigging slipping from the hook's jaw increase as the jaw angle grows.

Hooks need a retainer device that prevents rigging from slipping out of the jaw. There are some patented designs that accomplish this. The retainer allows rigging to slip into the jaw easily, but prevents it from slipping off the jaw. The retainer devices will not carry a load. They merely keep rigging in the jaw.

Chains requires inspection. When someone overloads a chain, the links will grow. That causes the inside radius of one loop to wrap around the next loop. An inspector can often tell very easily if a chain was overloaded by observing how easily the links articulate. Any stiffness between links suggests that wrapping took place and there is less load capacity.

There are load capacity charts for materials handling equipment and rigging (see note 11). Most load charts are for field use because a user does not need to make calculations before reading them. If a user must make a computation, there is a potential for error. Field use charts and tables include accepted safety factors, also called design factors. The charts and tables display the design/safety factors and other considerations. Engineering charts and tables are not intended for use in field operations and decisions. Engineering tables typically require computations and specialized knowledge for their use. These tables allow engineers to make interpretations to fit specialized situations. Tables 15-8 through 15-10 are examples of field tables. OSHA publishes tables of load capacity for many kinds of slings and sling materials (see note 11).

Examples of rigging will illustrate some important rigging principles.

Example 15-4 The angles formed by the legs of a sling affect the actual load each leg carries. Figure 15-7 illustrates this. A basket hitch sling supports a 1,000-lb load. Each vertical leg carries 500 lb. A choker hitch sling carries the same load but the single vertical element carries the entire 1,000-lb load. When each leg of the choker hitch forms a 60° angle with vertical (30° angle with horizontal), the load in each of the legs increases significantly. To determine the load in each leg, F_1, one can sum forces in the vertical direction, y.

$$F_y = 0 = 1,000 - (2\,F_1 \times \cos 60) = 1,000 - (2\,F_1 \times 0.5);$$

$$F_1 = 1,000 \text{ lb in each leg}$$

Example 15-5 A hoist with 10,000-lb capacity will lift a 7,500-lb (3.75 ton) load. A wire rope sling will lift the load. If the lift uses a vertical hitch, what size rope is needed to lift the load safely? Consider two kinds of ropes:

(a) 6 × 19 EEIPS, IWRC (independent wire rope core) wire rope with a mechanical splice

(b) polyester rope

TABLE 15-8 Rated Load for Grade 80 Alloy Steel Chain Slings (Vertical and Bridle Hitches)

		Single Leg Slings	Double Leg Bridle Slings and Single Basket Slings		
			Horizontal Angle[a]		
Nominal Chain Size		90 degrees	60 degrees	45 degrees	30 degrees
inches	mm	lb	lb	lb	lb
7/32	5.5	2,100	3,600	3,000	2,100
9/32	7	3,500	6,100	4,900	3,500
5/16	8	4,500	7,800	6,400	4,500
3/8	10	7,100	12,300	10,000	7,100
½	13	12,000	20,800	17,000	12,000
5/8	16	18,100	31,300	25,600	18,100
3/4	20	28,300	49,000	40,000	28,300
7/8	22	34,200	59,200	48,400	34,200
1	26	47,700	82,600	67,400	47,700
11/4	32	72,300	125,200	102,200	72,300

[a]The angles listed are measured from horizontal. For further information on this table, see www.osha.gov/dsg/guidance/slings/tables-figures.html.

What factor of safety (design factor) is there for each of these ropes?

The vertical hitch has one leg that carries the full, 7,500-lb load. From Tables 15-9 and 15-10, respectively, the sizes are

(a) 5/8 in. diameter

(b) 1½ in. diameter

Because these are field use tables, each includes a factor of safety or design factor. The factors of safety are 5 for both wire rope and the polyester rope.

Example 15-6 A lift will use a single leg sling with a vertical basket hitch. The sling material is ½ in., 6 × 19 EEIPS, IWRC wire rope. The angles formed by the legs are 30 degrees from vertical (60 degrees from horizontal) with a basket hitch. What is the largest load this setup can lift, if the sling has a mechanical splice? A hand-tucked splice?

The weakest component of a sling determines its capacity. The kind of splice that forms the loops on the ends determines a sling's efficiency. From Table 15-9, the maximum load for the mechanical splice is 5.5 tons. For the hand-tucked splice, the maximum load is 4.5 tons. The hand-tucked splice is less efficient than the mechanical splice.

15-8 CONVEYORS

Equipment

There are many kinds of conveyors used to move materials. There are roller, belt, screw, bucket, chain and overhead conveyors, gravity chutes, wheeled carts and hoppers, and others. Some are power-operated, while others depend on people or gravity to move items along.

Hazards

Some conveyors present hazards of material falling from them on people or items below. Conveyors and the structures

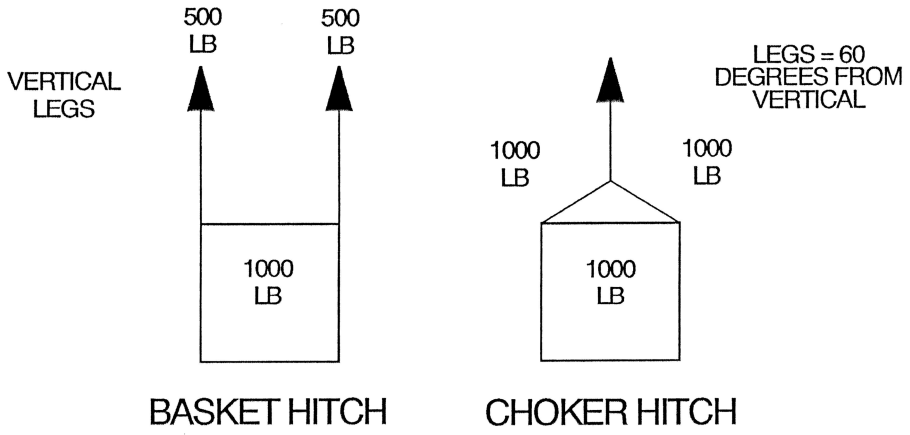


Figure 15-7. Comparison of basket hitch and choker hitch load capacities.

TABLE 15-9 Rated Load for Single Leg Slings 6 × 19 Classification, Extra Extra Improved Plow Steel (EEIPS), Grade Independent Wire Rope Core (IWRC) Wire Rope (Design Factor = 5; Rated loads in tons, 2,000 lb)

	Single-Leg Sling							
Hitch Type	Vertical			Choker		Vertical Basket		
Rope Diameter, in	HT	MS	S	HT	MS	HT	MS	S
¼	0.6	0.71	0.74	0.46	0.52	1.2	1.4	1.4
5/16	0.92	1.1	1.2	0.72	0.81	1.8	2.2	2.1
3/8	1.3	1.6	1.7	1.0	1.2	2.6	3.2	3.1
7/16	1.7	2.1	2.2	1.4	1.6	3.5	4.3	4.1
1/2	2.2	2.8	2.9	1.8	2.0	4.5	5.5	5.4
9/16	2.8	3.5	3.7	2.3	2.6	5.6	7.0	6.8
5/8	3.4	4.3	4.5	2.8	3.2	6.8	8.6	8.4
3/4	4.7	6.2	6.5	4.0	4.5	9.4	12	12
7/8	6.2	8.3	8.8	5.5	6.1	12	17	16
1	8.1	11	11	7.1	8.0	16	22	21
1 1/8	10	–	14	8.9	–	20	–	26
1 1/4	13	–	18	11	–	25	–	33
1 3/8	15	–	21	13	–	30	–	39
1 1/2	18	–	25	16	–	36	–	46
1 5/8	21	–	29	18	–	41	–	54
1 3/4	24	–	34	21	–	48	–	63
1 7/8	27	–	38	24	–	55	–	71
2	31	–	43	27	–	62	–	80

Notes: HT = hand-tucked splice; MS = mechanical splice; S = swaged or poured socket.For other information on this table, see https://www.osha.gov/dsg/guidance/slings/tables-figures.html

that support them may fail. For powered conveyors, there is the danger of people getting caught in moving parts, such as belts and chains. Some conveyors present pinch points and places where workers' hands and arms may become caught. There are catch points between materials and fixed parts of the conveyor or other fixed objects. Some conveyors, like belt conveyors, can extend for miles on elevated structures. To lubricate and maintain them, workers must have a walkway with a guard rail and access points to the conveyor components. There is the danger of falling from these access ways.

Controls

Conveyors that pass overhead should have overhead protection or some enclosure to prevent materials from falling on people below. From time to time someone must remove fallen materials and parts from the overhead structure. If workers must remove the material, overhead netting, screen, or other structural parts must be strong enough to carry the load of materials and people. In a classic case that tested the imminent danger rule of OSHA, the Supreme Court ruled on it in 1980. One worker fell to his death while cleaning fallen appliance parts from a wire mesh overhead protection system. After the screen failed, a second worker refused to perform the same task. The court ruled that the employer could not suspend the second worker for refusing the work without putting reasonable safeguards in place.

The moving parts of conveyors require guards to protect workers from machine dangers. This applies to powered conveyors with machine dangers that workers can reach. Pinch points created by belts and rollers, screw conveyors, chains and sprockets and other components must meet the machine guarding principles discussed in Chapter 13. There must be emergency shutoff controls at convenient locations along the conveyor. There must be warnings of dangers associated with conveyors where people may be present. Some conveyors need interlock switches and low speed or jog controls for servicing and maintenance.

Where objects suddenly come into view along a conveyor, workers may not anticipate their arrival. An object may create a pinch point danger. Audio and visual warning devices can alert people to the pending danger of oncoming materials. This problem sometimes occurs with enclosed chute and roller conveyors, especially those moving between floors.

Where access to conveyors requires elevated walking and working surfaces, there must be guardrails with standard protective features. Where conveyors have floor and wall openings through which people and material could fall, the openings must have guardrails with toe boards.

If workers must clear jammed materials from chutes or other conveyors, they should have tools, such as long poles suitable for the task. A worker about to enter a chute or

TABLE 15-10 Rated Load for Polyester Rope Slings, lb (Design factor = 5)

	Eye-and-Eye Sling - Hitch Type					
			Two-Leg Basket			
Rope Diameter, in	Vertical	Choker	90°	60°	45°	30°
1/2	1,000	750	2,000	1,700	1,400	1,000
9/16	1,300	980	2,600	2,300	1,800	1,300
5/8	1,600	1,200	3,200	2,800	2,300	1,600
3/4	2,200	1,700	4,400	3,800	3,100	2,200
7/8	3,000	2,300	6,000	5,200	4,200	3,000
1	4,000	3,000	8,000	6,900	5,700	4,000
1 1/8	5,000	3,800	10,000	8,700	7,100	5,000
1 1/4	6,000	4,500	12,000	10,400	8,500	6,000
1 5/16	6,500	4,900	13,000	11,300	9,200	6,500
1 1/2	8,400	6,300	16,800	14,500	11,900	8,400
1 5/8	9,900	7,400	19,800	17,100	14,000	9,900
1 3/4	11,400	8,600	22,800	19,700	16,100	11,400
2	14,400	10,800	28,800	24,900	20,400	14,400
2 1/8	16,200	12,200	32,400	28,100	22,900	16,200
2 1/4	18,100	13,600	36,200	31,300	25,600	18,100
2 1/2	22,000	16,500	44,000	38,100	31,100	22,000
2 5/8	24,200	18,200	48,400	41,900	34,200	24,200
3	31,200	23,400	62,400	54,000	44,100	31,200

Note: For other information on this table, see www.osha.gov/dsg/guidance/slings/tables-figures.html

similar conveyor opening must first lock out and tag out the power. A harness with lifeline may be necessary for the worker and an observer/assistant should be available for securing emergency help or rescue.

15-9 ELEVATORS, ESCALATORS AND MANLIFTS

Equipment

Some devices move people and goods vertically. Elevators are the most common. An elevator has a car, moved by cables or a hydraulic system. There are also elevators for materials only. One type of elevator that moves goods only is a dumbwaiter. People enter an elevator or place goods on them through an opening or door. Escalators are moving belts with components that form steps.

Manlifts are belts that move vertically. Along the length of its belt are small platforms that one person can stand on. There are handholds at appropriate heights above each platform. The belts move continuously at a fairly slow speed between two or more vertical locations. One can quickly step on a platform, grab the handhold and move to the other level.

Hazards

Major hazards for elevators include getting caught in the opening to a car when the car moves, getting caught in the doors, a runaway car, falling into the elevator shaft and becoming trapped in a stalled car. Others include tripping or falling on entry or egress if the car does not line up with the floor opening. Another danger is becoming crushed at the top or bottom of the shaft during service work.

For escalators, there is the danger of getting caught in the steps as they fold into a fixed end or between the edges of the steps and the side walls. An example is a draw string on the collar or hood of a child's clothes. A free end can get caught in the folds of an escalator step, tighten around the child's neck and strangle the child.

Hazards for manlifts include getting caught as one moves through a floor opening or falling from the platform.

Controls

Standards for elevators have existed for a long time. Today, many laws and codes at national, state and local levels govern elevators. Standards apply to design, construction, maintenance and inspection. Elevators, escalators, and manlifts require regular inspection and maintenance by trained people. Many states and municipalities require licensing of elevator inspectors. At regular intervals inspectors check cables, sheaves, brakes, and other mechanical components. Inspectors sign forms that attest to all components meeting standards.

Design standards incorporate safety features like brake systems, automatic braking if a cable fails, double doors for

CASE 15-3

1942, Albany, NY. The epitaph on Harry Edsel Smith's gravestone reads:

> Born 1903–Died 1942
> Looked up the elevator shaft to see if the car was on the way down.
> It was.

the car and openings, interlocks on all doors to stop the car if any doors are open. Interlocks on landing doors keep them closed until the car arrives. Access doors have detector switches to prevent closing on someone. Each size of car has a load capacity that affects the design and selection of various components. Elevators must contain emergency alarms and means of egress.

Escalators have emergency shutoff switches at each end. They have microswitches located at various points along and behind the side wall panels to stop the escalator if something gets caught between the steps and the sidewalls.

Because elevators, escalators, and manlifts create vertical openings in buildings, they provide paths for heat and smoke to pass from floor to floor. There are many fire regulations governing elevators, escalators, and manlifts and the openings for them.

An accident involving a dumbwaiter in a restaurant illustrates the importance of safeguards. The dumbwaiter moved food and dishes from the kitchen on a lower level to the dining room above. Employees locked out the interlock switches linked to the access doors. That left doors open. One employee stuck his head in the opening to see if the dumbwaiter was coming. His head became crushed between the door opening and the moving car. He died from the injuries.

15-10 BULK MATERIALS, EXCAVATION AND TRENCHING

Properties of Bulk Materials

When bulk materials, like grains, granular materials, sand and soil, become piled up, they will form a slope. The slope is called the *angle of repose*. The angle varies for different materials and largely depends on material cohesion. Under certain conditions bulk materials may hold together for a time, but eventually they form their own shape, the angle of repose. Moisture, vibration, particle size, and other factors affect when the angle of repose will form and what the angle will be. Chapter 10 discussed the angle of repose.

Bulk materials have some adhesion properties that allow them to support some load. However, the adhesion properties are not always uniform throughout a given pile of materials. Moisture, temperature, pressure, frost, vibration, and other factors can affect the adhesion and load bearing capabilities of bulk materials.

Hazards

When stored, particles in bulk materials may adhere to each other. When workers removed material from a pile, the disturbed edge of the pile may not take on the natural angle

CASE 15-4

September 30, 1992, Kansas City, MO. An elevator repairman, Johnnie Lay, with 11 years of experience, worked on a dumbwaiter at a nursing home. The dumbwaiter car had lodged in the shaft between two floors. Mr. Lay determined that the cable had unwound from the drum and wrapped around equipment in the pit. The pit was not large enough to provide access for repair work. Mr. Lay used a service door to the shaft. While rewinding the cable, the dumbwaiter fell several feet to the bottom of the shaft. The dumbwaiter impaled Mr. Lay's head in the pit, shearing off the lower half of his face, but leaving it connected by the skin. Although he survived, he had permanent scarring and nerve damage even after nine operations. He was unable to work again.

Mr. Lay sued the manufacturer of the elevator for a defective dumbwaiter. The case[a] involved arguments about the Missouri statute of repose, transfer of liability from the original manufacturer to a later owner, and an ultimate jury award of $5,000,000. An appeals court assigned one-third of the fault to Mr. Lay and the remainder to the manufacturer. There was an award of more than $9,000,000.

[a]*Lay v. P&G Health Care, Inc.*, W. D. 57678 (Mo. App. W.D. 12/12/2000).

of repose immediately. The wall of material could collapse suddenly and bury anyone working close to the material and below the top level.

A person may walk on a pile of some bulk material that supports the worker's weight. The person may encounter a location that does not have the same load-bearing capacity and sink into the material. Someone might also fall into a pile of bulk material and sink into it because it cannot support the person's weight. Attempts to work free may simply sink the person deeper into the material. The material acts more like a fluid when disturbed. Many people know of this phenomenon from quicksand in movies and TV. There is a danger of suffocation if material seals breathing air from the face. In addition, the bulk material can compress around the chest and severely limit chest movement necessary for inhalation, also causing suffocation or asphyxia.

When there are excavations or trenching operations, vibrations from nearby equipment can cause soils or materials to collapse unexpectedly and without warning.

Controls

To prevent bulk materials from caving in on someone, the materials must have restraints. Options are shoring or sloping back the material to an angle more shallow than the natural angle of repose. Some standards require these protections at depths greater than 4 ft. Other standards may allow greater depths before requiring protections. Chapter 10 discussed shoring and trench shields. Shoring or other restraints must meet accepted engineering standards.

Workers who must work above bulk materials that cannot support the weight of a person should use protective guardrails and harnesses with lifelines. Two people should work together so one can perform emergency rescue tasks if the other falls into the material below. The second person should have a backup, if there is a need to approach the entrapped person. Emergency rescue equipment should be nearby.

For work involving bulk materials in enclosed spaces, there may be additional dangers related to breathable atmospheres. The space may require breathable air supplies or exhaust ventilation.

Excavation and Trenching

When there are excavation and trenching operations, there are many other considerations. Adequate drainage will help prevent accumulation of water that may reduce the strength of shoring or restraints. There must be barriers to prevent people from falling into an excavation. There should be daily inspections of excavations and restraining systems. Means of

CASE 15-5

July 28, 2010. Mount Carroll, IL. Three young men worked in Haasbach LLC's storage bins unclogging corn kernels that clung together, plugging drain holes at the bottom of the bins. The bins were half-filled with 250,000 bushels of wet and crusty corn. The corn was about 30 feet deep. They used shovels and picks to break up the clusters. The task was "walking down grain." Will Piper was 20, Alex Pacas, 19, and Wyatt Whitebread, 14. A conveyor at the bottom of the bin moved the corn to load railroad cars and empty the bin for the new, upcoming harvest.

The drain caused a cone-shaped hole to form near the center of the bin. The company supervisor instructed the boys to stay away from the center cone. The supervisor opened a second drain in the bottom of the bin. This formed a second cone-shaped hole.

First, Wyatt got caught in the second cone. The other two boys grabbed him under his arms to pull him out, but started sinking themselves. The corn soon covered Wyatt and then Alex, and came up to Will's chin.

Local firefighters and others began the rescue. Firefighters entering the bin used harnesses and lanyards. Others cut holes in the side of the bin to drain the corn. Rescuers jammed a plastic rescue tube around Will and then vacuumed the corn from inside the tube to clear him before pulling him out. Wyatt and Alex died of asphyxia before rescuers could save them.

OSHA fined Haasbach LLC $555,000 for 25 safety violations, including twelve willful violation. Another agency within the U.S. Labor Department also fined Haasbach $68,125 for violating child labor laws which prohibit anyone younger than 18 from performing hazardous work.[a,b]

OSHA has fought grain entrapment for several decades.[c] Yet, grain entrapment kills more than 25 workers every year in the U.S. The cases are preventable. The flowing grain acts like quicksand and engulfs a victim. The grain surrounds the body, puts pressure on the chest and prevents breathing.

[a] www.npr.org/2013/03/26/174828849/fines-slashed-in-grain-bin-entrapment-deaths

[b] www.publicintegrity.org/2013/03/24/12327/worker-suffocations-persist-grain-storage-soars-employers-flout-safety-rules

[c] www.osha.gov/SLTC/grainhandling/hazard_alert.html

CASE 15-6

October 1, 1980, Danville, IL. The following incident is an example of preventable cases repeated many times each year across the United States.

A worker was part of a five-man crew of a small company. The crew was installing metal drainage pipes in a ditch. The worker's father ran a backhoe in the operation. The worker was in a trench about 8 feet deep. According to a sheriff's investigator, apparently the worker got his foot caught between the drainage pipe and the dirt wall of the ditch. About that time, the wall caved in on top of him, completely covering him. There was no shoring or trench shield in the ditch.

The worker's father, two brothers and another co-worker worked to dig out the buried worker. By the time they got him out, he was dead. The coroner determined that asphyxia was the cause of death.[a]

[a]Champaign-Urbana, IL, *News-Gazette*, October 1, 1980.

emergency egress are necessary. Safety procedures may require tests of atmospheres to determine if air quality is adequate. If the quality is inadequate, there is a need for supplied air or exhaust ventilation. Test data will show if there is a lack of oxygen or the presence of hazardous gases, fumes, or dusts.

There must be walkways and bridges with standard guard rails for people to cross over an excavation. Chapter 10 discussed excavations and trenching.

15-11 STORAGE OF MATERIALS

Hazards

Some of the main hazards of stored materials are items falling on someone below them, tripping or running into items protruding into traffic ways or aisles, piled materials tipping over, and physical damage to storage racks or piled materials by materials handling equipment.

Poorly stored materials create the potential for injury and damage. Effective and organized storage reduces operating and management costs and losses from damaged items.

Improper segregation of materials may create additional hazards from fire, explosion and corrosion. Refer to Chapter 16.

Controls

The old adage "a place for everything and everything in its place" is important when controlling material storage hazards. Well-planned, organized, and maintained materials storage areas reduce costs. There is a wealth of specialized equipment for solving materials storage problems.

Proper stacking is another control. Many kinds of materials have some form of packaging. The packaging or the material inside can hold only so much weight before it crushes. When storing items on damaged or crushed containers, there is a greater chance of items tipping over. The higher the materials are stacked, the higher the center of gravity and the less force required to tip a stack over.

Another control for some stored items is cross-ties. Cross-ties help interlock items and prevent tipping. Common materials with cross-ties are lumber and bagged materials.

Another control is stepping back materials. When someone stacks materials several rows deep and several rows high, the front tier has a tendency to tip over. Cross-ties may help, and stepping back the rows may help more. Stepping back materials means starting each higher row farther back from the front edge of the row below.

Retaining walls can help keep bulk materials from spreading out or collapsing. A sudden collapse of a bulk material pile may cover someone or damage nearby equipment. The retaining walls function like shoring. They must have adequate strength and bracing.

Racks keep many materials from falling. There are special racks for bar stock, piping, drums, rolls, and palletized materials. The racks must have sufficient strength to support the loads placed on them. The Rack Manufacturers Institute (RMI)[12] has structural standards and test procedures for rack stability.

It is not uncommon for industrial trucks to run into racks. Protective barriers installed along the floor near rack columns can reduce the likelihood of physical damage to the racks. Stiffeners can add strength, even if struck by vehicles. Racks should have designs that keep them standing, even if damaged by a vehicle. There should be a schedule for inspection of storage racks to identify damage and initiate repair.[13]

There must be enough aisle space between racks and items stored openly. The aisles should allow vehicles to place materials on racks or remove them safely. Because aisle width is an important economic consideration in storage facilities, special vehicles can minimize aisle width requirements.

Aisles for walking and for materials handling vehicles should have clear markings. Usually, they are separate aisles. Stored materials must not protrude into marked aisle spaces. If materials are in elevated positions near aisles and potentially unstable, the materials require restraints, such as netting

or other blocking means. In retail facilities, storage of goods about customer height potentially requires restraints. Customers injured by falling items have a potential lawsuit against the retailer.

Fire protection for stored materials will vary with the type and amount of materials, building design and other factors. Chapter 16 discusses fire protection.

EXERCISES

1. A box is 8 ft high, 4 ft deep and 6 ft wide and weighs 270 lb. A worker pushes on the box at a location midpoint along the width and 5 ft above the floor. The coefficient of friction between the box and floor is 0.53. Determine what value of the pushing force P will cause
   (a) tipping (rotation about the edge along the floor opposite the worker)
   (b) sliding
2. A worker picks up boxes from the floor and places them on a conveyor. This activity will occur every 30 s. The boxes, weighing 23 lb each, are 15 in. forward of the worker's ankle midpoint. The conveyor is 38 in. high and 35 in. forward from the worker's ankle midpoint. The lift is directly forward without twisting. The boxes have hand-hold cut-outs located 5 in. from the box bottom. Determine the RWL and LI for this activity for the origin and destination positions.
3. For the activity in Exercise 2, is the activity acceptable or are controls needed to prevent lifting injuries? If controls are needed, what kind would you recommend?
4. A 12,000-lb load is to be lifted with a sling. For the conditions in each of the following cases, determine what size chain or rope is needed:
   (a) grade 80 alloy steel chain, double leg basket sling, with legs at a 45° angle with vertical
   (b) single legged choker sling, 6×19 EEIPS, IWRC rope, mechanical splice
   (c) polyester rope, vertical hitch
5. A sling is used to lift a 1,000-lb load. If the sling is rigged as a choker and the legs below the choke point form an angle of 30° with the vertical, what load is carried by?
   (a) each leg
   (b) the vertical portion
6. A mobile hydraulic crane (refer to Figure 15-4) will be used to lift material. The tires are fully inflated. The ground is level and firm. Determine what load can be safely lifted for each of the following conditions:
   (a) Boom length: 40 ft
   Radius of load: 20 ft
   Boom position: over side
   Outriggers: 50% extended
   (b) Boom length: 80 ft
   Radius of load: 45 ft
   Boom position: centered over front
   Outriggers: 50% extended

REVIEW QUESTIONS

1. Name one material handling hazard associated with each of the following and give a control for that hazard:
   (a) environments where materials handling tasks are performed
   (b) maintenance of materials handling equipment
   (c) loading of materials handling equipment
   (d) securing loads
   (e) movement of material and materials handling equipment
2. How can the following contribute to injury associated with manual lifting?
   (a) size of load
   (b) raising a load overhead
   (c) frequency of lifting
   (d) asymmetrical loads
3. Explain how one can use RWL and LI in deciding if a lifting task is acceptable or needs design changes.
4. Describe two hazards and applicable controls related to the use of:
   (a) jacks
   (b) hand-operated materials handling vehicles
   (c) powered materials handling vehicles
   (d) hoisting apparatus
   (e) conveyors
   (f) elevators
   (g) escalators
   (h) manlifts
5. Define ROPS and FOPS and describe what protection each provides for powered materials handling vehicles.
6. What does the acronym LID stand for? Explain the function of an LID.
7. Identify at least one hazard and associated control for the following rigging components:

(a) ropes

(b) hooks

8. Can steel wire ropes store dangerous amounts of energy due to elasticity during loading?
9. Describe two main hazards associated with bulk materials. Identify an applicable control for each hazard.
10. Define the angle of repose and its significance for the safety of bulk materials and excavations.
11. Explain how a person can suffocate in bulk materials even though the person's head remains above the materials.
12. Name five controls to prevent accidents related to storage of materials.

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CHAPTER 16

FIRE PROTECTION AND PREVENTION

16-1 INTRODUCTION

The Fire Problem

Each year, there are major fire-related losses in the United States. In 2013, there were more than 1.2 million reported fires. These fires caused 3,240 civilian deaths and 15,925 injuries. The total property loss was $11.5 billion. Most fires involve structures. About 15% of fires involve vehicles and these are conservative figures.[1] The costs do not include many indirect costs, such as litigation, investigation, and other costs borne by society.

Most deaths from fires do not result from burns. Burns cause only about one-fourth of fire-related deaths. Nearly two-thirds of all fire-related deaths result from inhalation of carbon monoxide, smoke, toxic gases, and asphyxiation. About one-tenth of the deaths are from mechanical injuries, such as injuries from falls or falling material.

The overall death rate in the United States from fires is about 12.4 per million population and decreasing. In 1979, the death rate was 34.4. Children under 5 and adults older than 40 have fire death rates greater than the population average. Death rates increase exponentially with age for those above 40. The death rate is 49.2 for those older than 85.[2]

The death rate in the United States is about average among many developed countries. For example, some European countries (Switzerland is the lowest at 2.2) have a much lower rate. Singapore is 2.3. Others have rates higher than the United States. The death rate continues to decrease worldwide. Many factors, including building construction, affect the rates and the rate of decrease.

Studies show that deaths in fires are often alcohol-related. In one study, evidence suggested that more than 80% of the victims had been consuming alcohol. Another study looked at age and blood alcohol level for fire victims. For those victims aged 30–60 years, about one-quarter had no alcohol content in the blood and about two-thirds had an alcohol content greater than 0.10%.

Most fatal fires involve one or two victims. However, large losses get the greatest attention. The greatest losses have occurred in places of assembly. Table 16-1 lists the fires in the United States with the greatest loss of life.

Most fatal fires involve residences. However, fires occur in many kinds of buildings and in vehicles. The National Fire Protection Association publishes fact sheets related to many kinds of structures and other factors involved in fires. Examples are lightning strikes and fires, clothes dryers, brush and grass fires, fire costs, and children playing with fire.[3]

Causes of Fires

There are many causes of fires. The causes differ by building occupancy type. Heat and flames are frequent sources. In civilian fires with fatalities the leading causes of ignition are cigarettes (35%), heating and cooking equipment (7%), matches, lighters and candles (5%), and car crashes (4%). Table 16-2 lists the leading causes of industrial fires.

Arson

Estimates of direct losses due to arson and incendiary fires in the United States range as high as $1-3 billion each year. The reasons for arson vary from financial problems that might be resolved through an insurance claim, to anger with an employer, school or other person and to vandalism, and other problems. This discussion will not cover prevention of incendiary fires. There has been much research and study of arson cases, and most insurance companies apply specific actions that can reduce arson opportunities and potential losses. Application of fire protection designs and systems will help reduce losses for all fires.

Improving Fire Prevention and Protection

The Great Chicago Fire of 1871, many fires before it, and many since have stimulated research and action. As a result, we can prevent many fires today and minimize loss and damage. However, some still ignore the available knowledge, laws, and standards. Decision-makers sometimes cut initial costs for fire prevention measures in the hope that fire

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TABLE 16-1 Major U.S. Fires and Their Death Tolls

Date	Location	Deaths	Summary
10-7-1871	Peshtigo, WI	1,200 or more	1.2 million or more acres burned. 17 towns burned. The fire carried 20 miles across a body of water (Green Bay).[a]
10-7-1871	Chicago, IL	About 300	The Great Chicago Fire was one of the most famous fires in U.S. history. The fire burned 17,000 buildings. Wood sidewalks in the city were just completed. The fire left 100,000 homeless.[b]
12-30-1903	Chicago, IL	602	Chicago Iroquois Theater (led to new assembly design standards)[c]
3-25-1911	New York City	145	Triangle Shirtwaist Factory fire. Many victims jumped to their death. Led to new building codes for workplaces.[d]
7-6-1944	Hartford, CN	168	Ringling Brothers Circus tent fire. 68 children died. 487 people injured.[e]
12-1-1958	Chicago, IL	95	Our Lady of Angels School fire. 92 children died. Led to changes in school life safety codes.[f]
5-28-1977	Southgate, KY	165	Beverly Hills Supper Club fire. Resulted in code changes for food and casino places of assembly.[g]
11-20-1980	Las Vegas, NV	85	MGM Grand Hotel. Fire started in food buffet. Flame front traveled across the casino area faster than one can run. Many guests trapped in rooms. Led to hotel sprinkler standard in Nevada.[h]
12-4-1980	White Plaines, NY	26	Stouffer Hotel fire led to revised hotel construction standards.[i]
9-11-2001	New York City	3,000+	Terrorist plane crashes into World Trade Center led to fire and collapse. Led to changes in high rise construction and U.S. national security.[j]

[a]Gess, Denise and William Lutz, Firestorm at Peshtigo: A Town, Its People, and the Deadliest Fire in American History, Henry Holt & Co., New York, 2002.
[b]Bales, Richard, The Cause of the Great Chicago Fire and the Myth of Mrs. O'Leary's Cow, McFarland Publishing Co., Jefferson, NC, 2002.
[c]Brandt, Nat, Chicago Death Trap: The Iroquois Theatre Fire of 1903, Southern Illinois University Press, Chicago, 2006.
[d]Stein, Leon, The Triangle Fire, Caroll & Graf Publishers/Quicksilver Books, New York, 1985; Von Drehle, David, Triangle: The Fire That Changed America, Grove Press, New York, 2003
[e] www.youtube.com/watch?v=zHlB8FLqR9Q; www.circusfire1944.com/; www.hartfordhistory.net/circusfire.html
[f]Cowan, David and John Kuenster, To Sleep with the Angels: The Story of a Fire, Ivan R. Dee, Lanham, MD, 1998; www.olafire.com/CoronersJury.asp; http://www.olafire.com/NFPAReport.asp
[g]Webster, Robert with David Brock, and Tom McConaughy, Beverly Hills Supper Club: The Untold Story of Kentucky's Worst Tragedy, Saratoga Press, LLC, Saratoga, 2012; Elliot Ron, Inside the Beverly Hills Supper Club Fire, Turner, New York, 2010; http://fire.nist.gov/bfrlpubs/fire77/PDF/f77009.pdf (NIST Report)
[h]/www.youtube.com/watch?v=4o8dRs1R6O0; http://www.clarkcountynv.gov/Depts/fire/Pages/MGMHotelFire.aspx
[i] www.nytimes.com/1982/01/13/nyregion/investigator-called-stouffer-s-inn-fire-accidental.html
[j] www.nist.gov/manuscript-publication-search.cfm?pub_id=909017; www.nist.gov/el/disasterstudies/wtc/wtc_publications.cfm

will not strike in the future. Like other standards, fire codes are minimums. In many cases, one can exceed them.

Outbreaks of fire were an everyday occurrence in Rome and led to the first known fire fighting organization, the Corps of Vigiles. Devastating fires in early European cities led to equipment improvements. The introduction of fire engines and pumpers in the sixteenth century began to replace bucket brigades. In 1678, Boston created the first paid fire department in the United States. Public water systems in cities emerged to provide adequate water supplies, including that needed for fire fighting. The early building codes of the seventeenth century focused on an adequate supply of ladders and buckets. Later codes grew in complexity during the nineteenth and twentieth centuries. Later codes covered building design to control fire spread, water supply and safe exiting by occupants. Spurred by disasters like the Chicago Fire, zoning ordinances addressed

CASE 16-1

August 12, 1953, Livonia, MI. The biggest industrial fire in history occurred at the General Motors Detroit Transmission Division Hydra-matic plant. The fire started when some outside construction workers using an oxyacetylene cutting torch ignited a conveyor dip tank containing a highly flammable liquid. One story reports that a welder's torch ignited an oily rag that became caught on the conveyor line carrying the flame down the line. Within 15 to 20 minutes, the fire had spread through the 1.5 million square foot plant (34 acres); 4,200 workers escaped. Six died and 15 had serious injuries. The fire totally destroyed the plant.[a]

The fire led to new fire-containing design features. The primary new feature was use of smoke and heat vents to help isolate a fire in horizontal construction.[b]

[a]https://history.gmheritagecenter.com/wiki/index.php/Biggest_Industrial_Fire_in_History
[b]http://hpac.com/fire-smoke/considerations-use-smoke-and-heat-vents

CASE 16-2

June 30, 2013, Yarnell, AZ. Lightning ignited a wildfire at Yarnell Hill on June 28. Strong winds pushed the fire from 300 acres on June 30 to more than 2,000 acres. High temperatures and drought conditions contributed to the fire spread. Officials ordered the evacuation of Yarnell and its population of 700.

Firefighters from the Granite Mountain Hotshots of the nearby Prescott Fire Department were fighting the fire. The erratic fire movement apparently trapped the team. They deployed fire shelters and heat- and smoke-resistant enclosures. Nineteen firefighters lost their lives. This was the greatest loss of firefighters in a wildfire in many years.

Investigators believe the firefighters became cut off from their escape route. The winds moved the fire in their direction at 10–12 mph. Within a couple of minutes the route was in flames. The rapid expansion of the fire, problems with some communication equipment and other factors may have led to the tragic loss of life.[a]

June 29, 2015. The Arizona State Forestry Division reached a legal settlement in two cases with the families of the 19 fire fighters. Included was $600,000 in compensation. The settlement also acknowledged that commanders made misguided decisions that put the fire fighters at great risk.[b]

[a] www.iawfonline.org/Yarnell_Hill_Fire_report.pdf

[b] www.nytimes.com/2015/06/30/us/arizona-reaches-settlements-with-kin-of-19-who-died-fighting-wildfire.html?_r=0

land use. Zoning ordinances limit the amount of land that buildings can occupy. They set minimum distances between buildings to help prevent fire jumping from one property to the next. Zoning ordinances also set standards for adequate access routes for fire equipment.

Fire Codes and Standards

In the United States today there are many fire codes. Most cities have their own, often incorporated into building codes, zoning, and other ordinances. Most states have similar codes that apply when local governments have not adopted their own standards. Most local governments adopt codes developed and maintained by standards organizations. There are several model building codes in the United States, and they incorporate design requirements to minimize the chances of fire occurring, preventing fire from spreading and assure exiting by occupants. One example is the *International Building Code* (IBC), which resulted from the merger of three previous codes. The National Fire Protection Association (NFPA) began publishing a building code, now known as *NFPA 5000: Building Construction and Safety Code®*.

In addition, NFPA publishes many standards for a wide range of fire prevention, protection, engineering, and extinguishment matters. The name of this collection of standards is the *National Fire Code*. Each element of this collection has an identifying number. For example, NFPA 101 is the *Life Safety Code*, which addresses the safety of occupants and safe egress. There is a separate committee for each of the many codes and each committee continually reviews and updates a code's provisions. The *National Fire Code* is the primary source of standards in the United States for matters associated with fire. Other standards include model building codes and local codes.

The Society of Fire Protection Engineers (SFPE) publishes the *SFPE Handbook of Fire Protection Engineering*. It covers many details for engineering design of buildings, extinguishing systems and related matters. It explains fire-related calculations, fire risk analysis, and other technical concepts.

TABLE 16-2 Leading Causes of Industrial Fires[a]

Percent of Fires	Causes
23	Electrical (wiring and motors, poor maintenance of equipment)
18	Smoking materials
10	Friction (bearings, jammed machines, etc.)
8	Overheated materials
7	Hot surfaces (heat from boilers, furnaces, ducts, lamps, etc.)
7	Burner flames (open flame equipment)
3–5	Combustion sparks
3–5	Spontaneous ignition
3–5	Cutting and welding
3–5	Fire from nearby facility
3–5	Arson
1–2	Sparks
1–2	Chemical action
1–2	Lightning
1–2	Molten substances

Note: [a]Based on a Factory Mutual Engineering Corporation study of 25,000 fires over 10 years.

16-2 THE PHYSICS AND THE CHEMISTRY OF FIRE

Combustion

Fire is the rapid oxidation of material that emits heat and light. Combustion is an exothermic (gives off heat), self-sustaining

reaction involving a solid fuel, a gaseous fuel, or both. A fuel is any combustible material, most often the reaction is oxidation of a fuel by oxygen in air. Most often combustion involves the emission of light. Solid fuels usually appear to glow or smolder. Gaseous fuels usually emit a visible flame.

Ignition

Ignition is the initiation of combustion. Each material has some minimum temperature, called the ignition temperature, that it must reach for ignition to occur. Piloted ignition occurs when some external source, such as a flame, spark, ember or heat, causes ignition. Auto-ignition, also called spontaneous ignition or spontaneous combustion, occurs when there is no external source. The piloted ignition temperature of a fuel is lower than the auto-ignition temperature.

Heat buildup resulting from the oxidation of organic material is the usual cause of spontaneous combustion or auto-ignition. Bacteria and decomposition can contribute to the process in some materials. The material must reach the auto-ignition temperature and have enough oxygen for combustion. In general, agricultural products that have a high vegetable oil content are susceptible to auto-ignition. When left on open piles, oily rags from furniture finishing and other activities have led to many fires.

Fire Triangle and Pyramid

The components necessary for fire or combustion are: (a) a fuel; (b) a source of oxygen; and (c) a source of heat or flame or some minimum temperature. Once combustion starts and there are sufficient amounts of the three components, combustion will continue. Figure 16-1a illustrates these three components as the fire triangle. Technically, this model is correct for glowing combustion at the surface of solid fuels. Sources of oxygen are air, compressed air, liquid or solid oxygen and certain other chemicals. There are many kinds of fuels. Paper, wood, and cloth are examples of ordinary combustibles. There are also flammable liquids and gaseous fuels. Fuels can even be solids, like metals. Examples of heat sources are sparks, arcs, hot surfaces, and open flames.

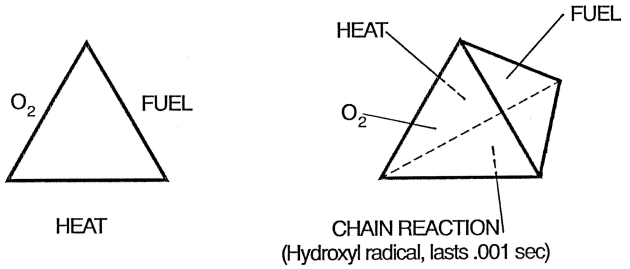


Figure 16-1. (a) The fire triangle and (b) the fire pyramid help in remembering the components involved in combustion.

During the process of combustion of vapors and gases in which there is a visible flame, a better model is the fire pyramid. Some call this the fire tetrahedron, since there are three sides and a base in the fire pyramid concept. Figure 16-1b shows a fourth component, production of hydroxyl (OH) radicals. An uninhibited reaction breaks down molecules into hydroxyl radicals. They last for an extremely short time, typically about 1 ms.

Heat and Heat Sources

The temperature necessary to sustain combustion varies for different materials. Combustion of ordinary hydrocarbons occurs at temperatures around 3000 °F, whereas some metals burn at temperatures of 5000 °F or higher. In the exothermic process of combustion, the amount of heat given off is dependent on the fuel. Each kind of fuel has an energy value or heat value per unit weight. That is the heat of combustion. For example, carbon monoxide contains 4,300 BTU/lb, paper has about 8,000 BTU/lb, gasoline about 19,000 BTU/lb, and hydrogen more than 51,000 BTU/lb.

The rate of heat produced during combustion depends on the rate of combustion. Data on combustion are often available for common fuels burned in air. Heat production increases significantly when there is an enriched oxygen supply. That occurs when there is high pressure air or gases with oxygen content greater than normal atmospheres with 21% (160 mm Hg partial pressure) oxygen. In enriched oxygen environments the ignition temperature may be lower than in normal air. Limited data are available on enriched combustion.

If there is not enough oxygen available, some fuels will not burn completely. Not only will the rate of combustion slow, but partially burned fuel will become airborne. A very common product of combustion that could oxidize further is carbon monoxide. Much of the content of smoke is unburned or incompletely burned fuel. If a new source of oxygen reaches the fire, the rate of combustion can increase rapidly. For example, in a closed, smoke-filled space, someone may open a window or door. Or a fire may break through a wall or ceiling and allow a supply of air to rush in. A flame front may actually travel very quickly along the new mixture of airborne fuel and air. In fact, the flame front may move faster than a person can run (see Case 16-1). A back flash occurs in a building fire when someone opens a window or door that produces sudden combustion of smoky air.

The rate of heat production and the location of combustion change constantly during a fire. The total heat produced during a fire is the product of the weight of fuel consumed and the heat of combustion for the fuel. For example, if a fire consumed 20 lb of gasoline (a little more than 2 gal) in a fire, the total heat produced would be 20 lb $\times$ 19,000 BTU/lb = 380,000 BTU. About 50 lb of paper would produce the same amount of heat but the gasoline would burn much more quickly.

A fire transfers heat to the surroundings by convection, radiation, and conduction. For most fires, heat transfers to the surrounding air by convection. Because of large temperature differences between the combustion process and the air entrained into the process, tremendous upward air currents can occur. The thermal gradient creates the upward movement of hot gases.

A fire loses a lot of heat through radiation. Radiation is highly dependent on geometry. One body must "see" the other for radiative heat transfer to occur. We do not feel the heat of the sun's rays when we stand in the shade of a tree because the tree prevents our body from "seeing" the sun. The surfaces surrounding a fire in a room "see" the fire and absorb much of the heat. As the surfaces absorb the heat, the room surface temperatures go up. The surfaces of a building near a fire can ignite if their temperatures rise enough from the heat absorbed through radiative transfer. The surrounding surfaces may reach the ignition temperature of the surface material. Technically, the rate of radiative heat transfer is a function of the fourth power of the absolute temperatures of the surfaces involved.

Methods for Controlling Combustion and Extinguishing Fires

The theories for fire found in the fire triangle and fire pyramid give us insights into methods for extinguishing fire and stopping combustion. The fire triangle gives us three approaches. One can cool the fire; one can limit the oxygen supply; or one can remove the fuel. Cooling the fire reduces the temperature of the process or reduces the flame or heat source. Shutting off air to a fire can stop the combustion by limiting the oxygen supply. Sometimes one can shut off the fuel by closing a valve or letting the fuel burn completely. In oil fires an explosion can sometimes separate the flame from the fuel to stop the fire.

The fire pyramid yields a fourth approach. One can inhibit the reaction producing hydroxyl radicals.

Products of Combustion and Their Hazards

Depending on the fuel, the availability of oxygen and other factors, combustion can produce a wide variety of products. Not only does combustion produce flames, heat and smoke, but also it produces many kinds of gases. Smoke is technically very fine solid particles suspended in air. Smoke may include droplets of steam. Two of the most common gases of combustion are carbon monoxide and carbon dioxide. Carbon monoxide forms when there is not enough oxygen for complete combustion of the fuel. Carbon dioxide forms when combustion is complete. Other gases formed during combustion include hydrogen sulfide, sulfur dioxide, ammonia, hydrogen cyanide, hydrogen chloride, nitrogen dioxide, acrolein, and phosgene.

Carbon monoxide is a major cause of death in fires for two reasons. First, it is a very common product of combustion. Second, even low concentrations can be lethal. A concentration of 1.0% or higher can cause death in 1 min. or less. Carbon monoxide attaches easily to the hemoglobin of red cells in the blood. The red cells normally transport oxygen from the lungs to tissue throughout the body. Carbon monoxide does not release easily from the hemoglobin. That prevents the red cells from transporting the needed oxygen. At high carbon monoxide levels the oxygen supply to tissues of the body quickly deteriorates. Studies have found significant levels of carbon monoxide in fire fighters' bodies several days following a fire.

Carbon dioxide can contribute to fire-related deaths. At low concentrations, it is not harmful. It is a normal product of combustion in the cell metabolism of the body. An increased respiration rate is a physiological response to increasing carbon dioxide in the blood. When one exercises, the increase in carbon dioxide tells the body there is a need for more oxygen for the exercising muscles. Externally supplied carbon dioxide produces the same effect. However, in a fire, increased rates of breathing lead to inhalation of other combustion products that create danger for a person.

Lack of oxygen is another hazard in fires. A fire, particularly one in a confined space, may consume much of the oxygen available. As the normal 21% oxygen content declines, the capability of the hemoglobin of the red cells to transport oxygen to body tissues decreases. Reduced oxygen supply can impair tissue function. When affecting muscles, motor performance goes down. When affecting nerve cells, the lack of oxygen may impair motor performance and reduce mental processes. If the oxygen supply becomes low enough, unconsciousness results.

Other combustion gases can have a variety of effects. The most important factors are the toxicity of each material and the concentration. Some materials, like hydrogen cyanide, are highly toxic and can cause death when inhaled. Acrolein, for example, is a strong respiratory irritant and can cause death in small concentrations. Ammonia is an irritant to the eyes and nose and can contribute to breathing difficulties.

16-3 BEHAVIOR OF FIRE

General Movement of Hot Gases and Smoke

During a fire the hot gases and smoke will rise above the flame due to their lower density. The presence of smoke will have no significant effect on the movement of the gases coming from a fire. If the gases reach an obstruction when moving vertically, they will move laterally. The gases may find an opportunity to continue a vertical movement or cool sufficiently to move downward.

Due to an increase in temperature, gases in a fire will expand in volume. As the gases cool, they return to their original volume or near it. Combustion can create small overpressures in a closed space. The amount of overpressure can affect movement of gases into or out of the space.

Horizontal Movement

In a closed space, the hot gases rise until they reach a ceiling, where they form a layer floating above the cooler air. There is some mixing between the hot layer of gas and the cooler air below. Hot gases will move horizontally along the ceiling very quickly. Once the hot layer becomes confined, it will increase in thickness and push into the cool layer below. Figure 16-2 and Case 16-1 illustrate this concept. The mass of hot gas M entering the upper layer is related to the size of the fire:

$$M = ph^{3/2}/40 \qquad (16\text{-}1)$$

where

- M is in pounds per second
- p is the perimeter of the fire area in feet
- h is the distance from the floor to the base of the hot layer in feet

Equation (16-1) assumes that the fire is large enough for flames to reach the hot gas layer.

Vertical Movement

As noted, hot, expanded gases from a fire move vertically. In tall buildings the movement of heat and smoke is important. Several factors affect the vertical movement. These factors include tightness of construction, external winds, the difference between internal and external temperature, and the presence of vertical openings. Typical vertical openings are stairways, elevator shafts, and ventilation shafts. Vertical openings can create a stack effect, named after the movement of heat and smoke up a chimney or smoke stack. Some refer to this effect as the draft of a chimney or smoke stack.

Consider a tall narrow container. If the temperature inside the container is warmer than the temperature of air outside of it, a column of air outside will weigh more than one inside. The pressure at the bottom of the column inside the container will be less than that for the column outside the container. If the container has an opening at the bottom and at the top, the pressure outside the container will want to push air in at the bottom. Because the air inside is warmer and less dense, it will want to flow out at the top. The name for this phenomenon is the stack effect. There are pressure differences between the two adjacent columns of air. The pressure difference P_d between the bottom of the container and the top defines the draft or stack effect created:

$$P_d = 7.63H(1/T_o - 1/T_i) \qquad (16\text{-}2)$$

where

- P_d is inches of water
- H is the vertical distance between inlet and outlet in feet
- T_o is the absolute temperature of the external air in degrees Rankine
- T_i is the absolute temperature of the internal air in degrees Rankine

Equation (16-2) assumes standard pressure and air density.

If $T_o < T_i$, air will flow into the lower opening and out the top. If $T_o > T_i$, the air will flow into the top opening and out the bottom; if $T_o = T_i$, there is no air flow.

When there is a difference between inside and outside temperatures, there is some point between the top and bottom openings where the internal and external pressures are equal. This location is the neutral pressure plane. An overpressure from a fire inside a building will move the neutral pressure plane downward. If the temperature outside a building is less than inside, a vent opening can move the neutral pressure plane upward.

The location of the neutral pressure plane can influence the distribution and buildup of smoke in a tall building. However, the movement of heat and smoke in tall buildings is not fully understood. It is difficult to model. If air enters at the bottom near a fire, the fire can become more intense, adding smoke. External winds can change the patterns of movement. On a hot summer day, often the external air temperature is higher than the air-conditioned interior air. This reduces or eliminates the stack effect.

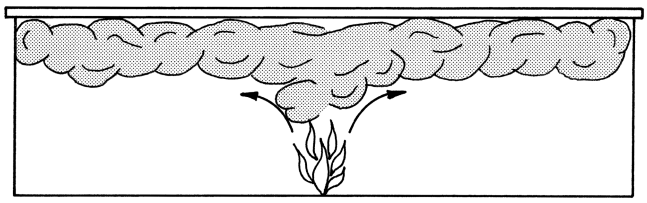


Figure 16-2. Hot gases build up at the ceiling and move laterally in horizontal buildings.

Smoke Produced

The amount of smoke produced in a fire is difficult to predict. Studies have shown that the rate of smoke produced is related to the perimeter of the fire and the height of a clear zone of air above the fire (see Figure 16-3). During a fire, the amount of smoke produced will diminish as the layer of clear air gets smaller. Reducing the size of a fire will decrease the amount of smoke produced.

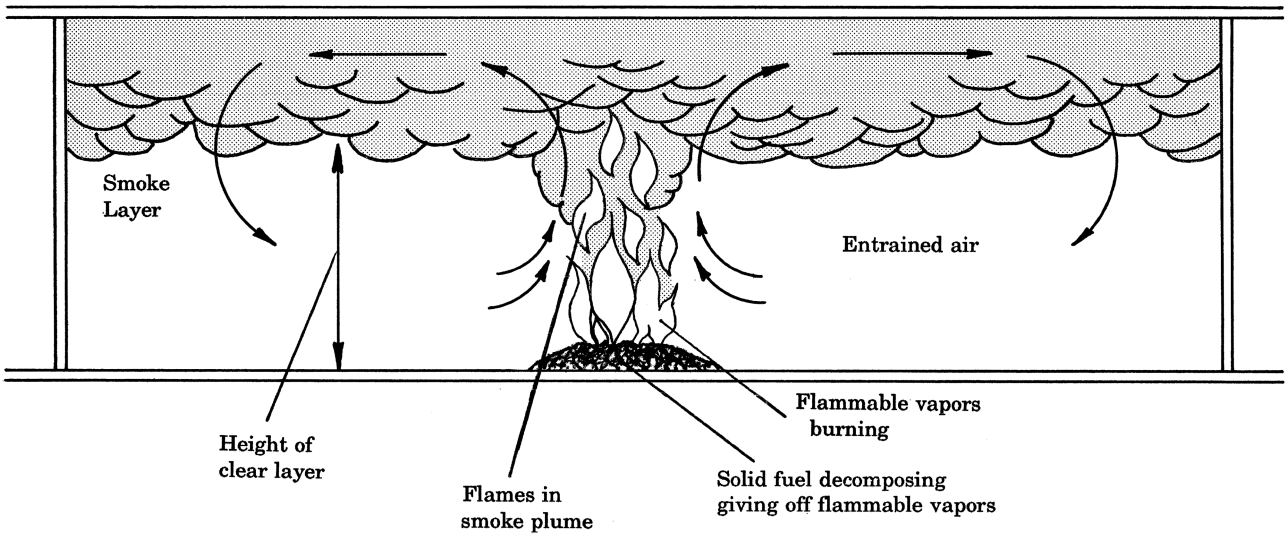


Figure 16-3. The rate of smoke production is a function of the fire perimeter and clear zone height.

16-4 FIRE HAZARDS OF MATERIALS

Flammable and Combustible Liquids

Classification Many of the common fuels, such as gasoline, diesel fuel, and heating oil, are in liquid form. Interest in the properties of these fuels resulted in a classification system and formulation of properties of liquid fuels.

NFPA developed a classification system for flammable liquids and combustible liquids (see Table 16-3) that uses flash point, vapor pressure, and expected ambient temperature conditions. A flammable liquid is a liquid with a flash point that does not exceed 100 °F based on testing by closed-cup test methods. A combustible liquid is a liquid with a flash point at 100 °F or higher using the same test methods. The flash point of a liquid is the lowest temperature at which the vapor pressure of the liquid is just sufficient to produce a flammable mixture at the lower limit of flammability. The flash point is the lowest temperature of a liquid in an open container at which vapors evolve fast enough to support continuous combustion. Laboratory test methods and other factors can affect flash point values.

TABLE 16-3 NFPA Classification for Flammable and Combustible Liquids[a]

Category	Description
Flammable Liquid	Flash point < 100 °F; vapor pressure < 40lb/in.^{2} at 100 °F
Class IA	Flash point < 73 °F; boiling point < 100 °F
Class IB	Flash point < 73 °F; boiling point ≥ 100 °F
Class IC	Flash point ≥ 73 °F and below 100 °F
Combustible Liquid	Flash point ≥ 100 °F
Class II	Flash point ≥ 100 °F and below 140 °F
Class IIIA	Flash point ≥ 140 °F and below 200 °F
Class IIIB	Flash point ≥ 200 °F

Note: The classification scheme uses boiling point to distinguish between Class IA and Class IB only.
[a]NFPA 30, *Flammable and Combustible Liquids Code*.

OSHA uses the definitions in Table 16-3.[4] The Department of Transportation (DOT) had used those definitions. However, to reach conformity with United Nations hazardous materials regulations, DOT changed its definition of flammable liquid. The upper limit for the flash point is now 141 °F.[5]

Several factors form the basis for the classes of flammable and combustible liquids in Table 16-3. Vapor pressure is a property of a liquid in a closed container. The atmosphere above the liquid is a mixture of air and vapors of the liquid. The portion of vapor that will form in this mixture is a function of the vapor pressure of the liquid.

The boiling point is the temperature at which the equilibrium vapor pressure of a liquid equals the total pressure on the surface. More simply, it is the temperature at which a liquid boils under some surrounding total pressure. Tables give vapor pressures of liquids at particular temperatures and normal boiling points (1 atm) of liquids.

A typical indoor comfort temperature is about 73 °F. In most locations an indoor temperature could reach 100 °F at some time. Moderate heating is necessary to produce higher temperatures to an arbitrary limit of 140 °F. Considerable heating is necessary to produce ambient temperatures above 140 °F.

Vapor Volume It is known that oxygen, most commonly in air, must be present with a fuel for combustion. If there is too much or too little fuel in the mixture of fuel and air,

combustion will not occur. Normally, flammable and combustible liquids themselves will not burn. A liquid fuel must vaporize.

Vapor volume is the volume of gas formed when a liquid fuel evaporates. The vapor volume computation uses other properties of the liquid and vapor:

$$V_v = \frac{8.33 \times \text{specific gravity of the liquid}}{0.075 \times \text{vapor density of the vapor}} \quad (16\text{-}3a)$$

$$= \frac{111 \times \text{specific gravity}}{\text{vapor density}} \quad (16\text{-}3b)$$

where

V_v is in cubic feet per gallon
8.33 is the weight (pounds) of 1 gal. of standard water
0.075 is the weight (pounds) of 1 ft^3 of air at standard temperature and pressure

Some tables listing properties of flammable and combustible liquids give vapor volume directly. Table 16-4 provides properties of several flammable and combustible liquids.

Flammable Limits The mixture of fuel and standard air necessary for combustion of fuel vapors must be within certain limits. The lower flammable limit (LFL) is the minimum concentration of vapor-to-air, below which propagation of a flame will not occur in the presence of an ignition source. The upper flammable limit (UFL) is the maximum vapor-to-air mixture above which propagation will not occur. Mixtures below the lower flammable limit are too lean, with too little fuel. Those above the upper flammable limit are too rich, with too much fuel. The term lower explosive limit is equivalent to LFL. The upper explosive limit is equivalent to UFL. Flammable limits vary somewhat with temperature and pressure. The flammable range is the mixture of fuel and air between LFL and UFL. Table 16-4 includes LFL and UFL values.

Examples Sometimes one must estimate whether evaporating fuel will form a combustible mixture. Such mixtures may result from a spill in a closed space or loss of flammable material in a manufacturing process. It is not always possible to make an exact determination, because vapors may not mix uniformly throughout a space. Vapors from a solvent tank may be heavier than air, evaporate at the surface of the liquid, slide over the edge of the tank, and concentrate near the floor. In another case vapors may be lighter than air and concentrate near a ceiling. For some computations of this type, it is useful to apply an adjustment factor for incomplete mixing and local concentrations.

Example 16-1 Consider the case of a child who used gasoline to clean his hands in a bathroom. The bathroom contained a gas water heater. While cleaning his hands, the gasoline vapor ignited and the child received severe burns. Assume the room was 6 ft wide × 10 ft long × 8 ft high.

(a) Assuming full mixing (uniform vapor/air mixture throughout the room), how much gasoline had to evaporate to reach a combustible mixture?

(b) Assume there was incomplete mixing (non-uniform vapor/air concentrations in the room) as the concentration formed near the igniter of the water heater. Apply an adjustment factor of 5 and estimate the minimal amount of vapor required to develop a locally combustible mixture in the room.

(c) Will the vapors of gasoline concentrate at the floor or at the ceiling when evaporating in air? How would one know?

The room volume is 480 ft^3. From Table 16-4, the LFL for gasoline is 1.4% in air. The vapor volume of gasoline necessary for combustion with uniform mixing is then $480 \times 0.014 = 6.72$ ft^3. From Table 16-4 the vapor equivalent of gasoline is 24 ft^3/gal. Thus, the minimum volume of liquid gasoline that must evaporate to produce the LFL is 6.72/24 = 0.28 gal.

For unequal mixing the estimated minimum is 0.28/5 = 0.056 gal., assuming a factor of 5 is a reasonable adjustment factor. This is approximately 14 tablespoons of gasoline.

From Table 16-4 the vapor density of gasoline is 3 to 4. Because the vapors are much denser than air, they will concentrate quickly at the floor, the location for ignition of the heating element of a gas water heater. To be safe with the estimate, an adjustment factor greater than 5 may be a better choice. Gasoline is very volatile and one would not want the vapor concentration to reach an ignition level.

Flammable Gases

Flammable gases refer to those gases that exist at standard temperatures and pressures (above the normal boiling point of a gas) and will burn in normal concentrations of oxygen in air. Flammable gases must combine in appropriate mixtures with air for combustion to occur. They must be at or above their ignition temperature to burn. Any substance that has a vapor pressure greater than 40 lb/$in.^2$ (absolute) at 100 °F in its liquid state is considered a gas. Like vapors of flammable and combustible liquids, the specific gravity of a gas can be important when analyzing fire potential. Full mixing in a space may not occur, but local concentrations may build up and reach combustible mixtures.

Nonflammable gases are those that do not burn in any concentration of air or oxygen. Inert gases are those that will not support combustion. Some gases, called reactive gases, will react with other materials in processes other than combustion. An example is chlorine reacting with hydrogen. Chlorine is a nonflammable (but toxic) gas and hydrogen is a

TABLE 16-4 PROPERTIES OF SOME FLAMMABLE LIQUIDS[a]

Liquid	Flash Point °F	Boiling Point °F	Ignition Temp. °F	Flammable Limits, Vol. % LFL	Flammable Limits, Vol. % UFL	Specific Gravity (Water = 1)	Vapor Density (Air = 1)	Vapor Volume (ft^3/gal)
Acetaldehyde	−38	70	347	4.0	60	0.8	1.5	58
Acetone	−4	133	869	2.5	13	0.9	2.0	44
Acrolein	−15	125	428	2.8	31	0.8	1.9	—
Allylamine	−20	128	705	2.2	22	0.9	2.0	—
Amyl acetate	60	300	680	1.1	7.5	0.9	4.5	22
Benzol (benzene)	12	176	928	1.3	7.9	0.9	2.8	37
Butadiene monoxide	<−58	151	—	—	—	0.9	2.4	—
Butyl alcohol	98	243	650	1.4	11.2	0.8	2.6	—
Butyl chloride	15	170	860	1.8	10.1	0.9	3.2	—
Carbon disulfide	−22	115	194	1.3	50	1.3	2.6	54
Cyclohexane	−4	179	473	1.3	8	0.8	2.9	30
Denatured alcohol	60	175	750	—	—	0.8	1.6	—
Dibutyl ether	77	286	382	1.5	7.6	0.8	4.5	—
Dichloroethylene-1,2	36	119	860	5.6	12.8	1.3	3.4	43
Diethylamine	−9	134	594	1.8	10.1	0.7	2.5	32
2,2-Dimethylbutane	−54	122	761	1.2	7.0	0.6	3.0	—
2,3-Dimethylpentane	<20	194	635	1.1	6.7	0.7	3.5	—
P-diokane	54	214	356	2.0	22	1.0+	3.0	39
Divinyl ether	<−22	102	680	1.7	27	0.8	2.4	—
Ethyl acetate	24	171	800	2.0.	11.5	0.9	3.0	33
Ethyl alcohol	55	173	685	3.3	19	0.8	1.6	56
Ethylamine	<0	62	725	3.5	14	0.8	1.6	50
Ethyl chloride	−58	54	966	3.8	15.4	0.9	2.2	46
Ethyl ether	−49	95	356	1.9	36	0.7	2.6	31
Gasoline	−45	100 to 400	536 to 853	1.4	7.6	0.8	3 to 4	24 to 32
Hexadiene-1,4	−6	151	—	2.0	6.1	0.7	2.8	—
Hexane	−7	156	437	1.1	7.5	0.7	3.0	25
Isopropyl alcohol	53	181	750	2.0	12.7	0.8	2.1	—
Jet fuel (JP-4)	−10 to +30	–	464	1.3	8.0	—	—	—
Kerosene	100 to 162	to 574	410	0.7	5	< 1	—	—
Methyl alcohol	52	147	867	6.07	36	0.8	1.1	80
Methylcyclohexane	25	214	482	1.2	6.7	0.8	3.4	26
Methyl ethyl ether	−35 51	374	2.0	10.1	0.7	2.1	—	
Methylethylketone	16	176	759	1.4	11.4	0.8	2.5	36
Naphtha V.M.& P.	28	212 to 320	450	0.9	6.0	<l	—	—
Nitroethane	82	237	778	3.4	—	1.1	2.6	46
Paraldehyde	96	255	460	1.3	—	1.0−	4.5	—
Pentane	<−40	97	500	1.5	7.8	0.6	2.5	29
Petroleum ether	<0 to 140	95	550	1.1	59	0.6	2.5	—
Propanol	−22	120	405	2.6	17	0.8	2.0	—
Propylene oxide	−35	94	840	2.3	36	0.8	2.0	—
Toluol	90	231	896	1.2	7.1	0.9	3.1	—
Turpentine	95	300	488	0.8	—	<1	1.8	—
Vinyl ethyl ether	<−50	96	395	1.7	28	0.8	2.5	—
Xylene-o	90	292	867	1.0	7.0	0.9	3.7	27

Note: [a]Most properties are from NFPA 325, 1994, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*.

flammable gas. Although their reaction will produce a flame, the reaction does not involve oxygen. Besides being combustible or reactive, gas toxicity is another hazardous property (see Chapter 24). Another hazard of gases relates to the Boyle-Charles law (see Chapter 19). There are other ways to classify gases based on physical properties and use.

Other Materials

Besides flammable and combustible liquids and flammable gases, there are many other kinds of materials that will burn. Some of the major ones are wood, metals, and plastics.

Wood Wood and wood products, like pulp, paper, and cardboard, will burn. There is considerable variation in the heat value of different wood species and products. During combustion, wood will char. In charring, wood forms a layer of partially burned material. This layer insulates material below it from the heat of combustion and slows the burning rate. In fact, wood can retain many of its structural properties in a fire for some time. The structural properties remain because of the insulating effect of the char formation.

The ignition and charring of wood have been studied. Ignition temperatures vary significantly, depending on the moisture content, density, and other factors. When wood burns, initially combustion drives moisture and other non-combustible gases from it. As combustion progresses, the wood temperature increases to produce water vapor and carbon monoxide. At first, burning wood absorbs heat. As wood reaches higher temperatures, flammable vapors and particulates form an exothermic reaction and form charcoal. In general, the ignition temperature of wood declines as combustion moves through these stages. Ignition temperatures for test blocks are on the order of 300–400 °F. Charcoal may ignite at significantly lower temperatures.

Metals Most metals will burn under certain conditions. Small cross-sections and fine particles will burn more readily than thick solids. Some metals are considered combustible because they are relatively easy to ignite. Combustible metals include magnesium, titanium, zinc, sodium, lithium, some radioactive metals, and others. Burning metals create special extinguishment problems. For example, dumping water on a titanium fire may add to the fire. The water may break down into oxygen and hydrogen. The oxygen can combine with titanium and hydrogen to become another fuel. Magnesium will burn in a carbon dioxide atmosphere. Aluminum, iron, and steel will not burn easily because they do not react with oxygen easily. Fine metal powders may ignite easily and explode like other dusts (see Chapter 17).

Plastics There is a wide variety of plastics, some with special additives to achieve particular properties. They vary in many ways, including fire-related properties. However, some generalizations illustrate their hazards. Most plastics have higher ignition temperatures than wood. Some have a rapid flame spread rate, and some ignite easily and burn rapidly. Many plastics produce dense black smoke during combustion, often due to additives that inhibit flammability. Like other materials, most plastics produce carbon monoxide and many also produce other toxic gases. During combustion, most plastics melt, which may result in drippings that spread the fire. Cellular plastics without flame retardants can create fast-spreading, high-intensity, dense-smoke fires.

NFPA Identification of Hazards of Materials

NFPA has developed a system for identifying fire hazards of materials.[6] The system presents information on labels and placards about three types of hazards. The system subdivides each hazard type into five levels of severity. The information helps fire fighters and others. The data appear in a four quadrant diamond symbol. As illustrated in Figure 16-4, three quadrants are for the three kinds of hazards: health, flammability, and instability. The lower, fourth quadrant contains special information and symbols. For example, one symbol is a W with a horizontal line through it. That indicates a material with a hazardous reaction to water and water is not a proper extinguishing agent. Another symbol is the radioactive pinwheel symbol (see Figure 22-2). Numbers in each quadrant give the degree of the hazard. General interpretations for degree of hazard are as follows:

0. No special hazards, therefore no special measures for fire fighting.

1. Nuisance hazards are present that require some care; use standard fire fighting procedures.

2. Hazards are present in the materials that require certain equipment or procedures for safe handling; use standard fire fighting procedures.

3. Fire can be fought using methods intended for extremely hazardous situations, such as unmanned monitors or personal protective equipment that prevents all bodily contact.

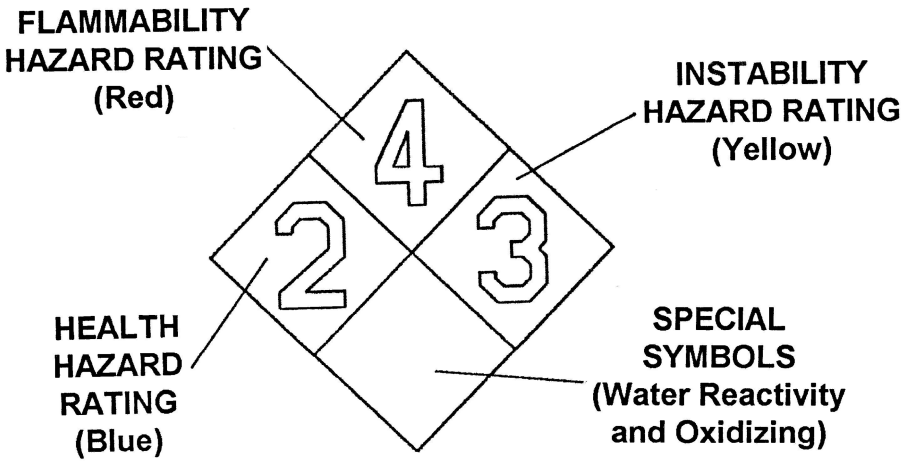
4. Too dangerous to approach with standard fire fighting equipment and procedures; withdraw and obtain expert advice on how to handle.

Figure 16-4 shows degree of hazard information. NFPA standards provide further data and interpretations for specific types of hazards.[7]

16-5 FIRE SAFETY IN BUILDINGS

Fundamentals

The Great Chicago Fire of 1871 provided at least two important lessons. One resulted from the inability of fire equipment to move down congested streets to a location where they could fight parts of the fire effectively. The other resulted from the rate at which the fire spread. The density of frame structures on lots was a big factor. Fed by the wind, fire leapt from building to building very quickly. Undoubtedly,



DEGREE OF HAZARD	HEALTH HAZARD RATING	FLAMMABILITY HAZARD RATING	INSTABILITY HAZARD RATING
4	Materials that, under emergency conditions, can be lethal.	Materials that will rapidly or completely vaporize at atmospheric pressure and normal ambient temperature or that are readily dispersed in air and will burn readily.	Materials that in themselves are readily capable of detonation or explosive decomposition or explosive reaction at normal temperatures and pressures.
3	Materials that, under emergency conditions, can cause serious or permanent injury.	Liquids and solids that can be ignited under almost all ambient temperature conditions. Materials in this degree produce hazardous atmospheres with air under almost all ambient temperatures or, though unaffected by ambient temperatures, are readily ignited under almost all conditions.	Materials that in themselves are capable of detonation or explosive decomposition or explosive reaction, but that require a strong initiating source or that must be heated under confinement before initiation.
2	Materials that, under emergency conditions, can cause temporary incapacitation or residual injury.	Materials that must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur. Materials in this degree would not under normal conditions form hazardous atmospheres with air, but under high ambient temperatures or under moderate heating could release vapor in sufficient quantities to produce hazardous atmospheres with air.	Materials that readily undergo violent chemical change at elevated temperatures and pressures.
1	Materials that, under emergency conditions, can cause significant irritation.	Materials that must be preheated before ignition can occur. Materials in this degree require considerable preheating, under all ambient temperature conditions, before ignition and combustion can occur.	Materials that in themselves are normally stable, but that can become unstable at elevated temperatures and pressures.
0	Materials that, under emergency conditions, would offer no hazard beyond that of ordinary combustible materials.	Materials that will not burn under typical fire conditions, including intrinsically noncombustible materials such as concrete, stone, and sand.	Materials that in themselves are normally stable, even under fire conditions.

Figure 16-4. NFPA symbol system for identification of hazards of materials. (Refer to NFPA 704.)

radiation, convection, and wind-blown sparks all played a large part in the process. As a result, people wrote rules for the layout of communities, streets, building sites, water supplies, and construction of buildings. Other fires added to these lessons and influenced today's standards as well.

The main goals for fire safety in buildings include:

(a) getting occupants out safely;

(b) minimizing property loss for structures and contents;

(c) minimizing interruption of operations.

Continual study to produce knowledge of fire behavior and building design will make it possible to reduce fire losses. Often the goal is to confine a fire to the site of origin, then to the building of origin. Through proper design of facilities, one can confine most fires to the floor and even the room of origin.

Site Planning and Accessibility

Fire departments and equipment should have access to all sides of a building. There should be adequate access roads even during peak traffic loads. Landscaping, external structures, and vehicle parking should not create barriers to access. The location of water supplies, hydrants, and valves should be convenient and support fire fighting strategies. There should be adequate pressures and quantities of water. If special hazards exist that require other kinds of extinguishing agents, the site plan should include those agents in adequate amounts and at effective locations. There should be shutoff valves for gas lines and supply lines for other fuels entering a facility. The shutoff valve locations should make them safe to operate in a fire.

An example is a vehicle driving away from a gas pump, catching a fuel hose, and starting a fire. If the shutoff is at the pump, it would be difficult to approach and shut off the fuel.

Separation of Structures

Buildings should have sufficient separation to minimize fire traveling from one building to another. Distance between buildings is one way to provide separation. Shielding by fire walls is another way. Other design features, such as parapets, minimal wall openings to adjacent buildings, fire-resistant door and window materials for openings, automatically closed doors, dampers and shutters, will all help limit fire movement between buildings. So will sprinkler systems and water curtains. Many factors affect design decisions intended to meet separation requirements. Type of construction, building height, size of exposed walls, building materials, and number of openings in building walls are merely a few considerations.

Building Construction

A building designer has a wide choice of materials and methods of assembly. The materials and the methods of assembly can affect the ability of a building to meet fire safety objectives and can also affect insurance premium rates.

Fire Resistance Ratings Fire resistance is a rating for building assemblies and elements based on laboratory tests. Given in units of minutes or hours, the fire resistance ratings indicate how long an assembly or element will withstand a particular test fire. One goal is confining a fire long enough to ensure escape and exiting of occupants. Another goal is limiting the spread of a fire.

Building Construction Classification There are many ways to classify buildings and the materials and methods of assembly. NFPA standards[8] classify types of building construction into categories based on building element, type of construction material, and fire resistance ratings of the materials. The classification scheme links to certain parts of building codes. The scheme is complex, but thorough in defining fire safety of many kinds of buildings, materials, and construction methods.

Building elements include exterior and interior bearing walls, interior and exterior nonbearing walls, columns, beams, girders, trusses, arches, floor-ceiling assemblies, and roof-ceiling assemblies.

Types of construction materials include non-combustible, limited-combustible, and combustible. The definitions provide detailed examples for each. Non-combustible materials will not ignite, burn, support combustion, or release flammable vapors in fire or when heated. A limited-combustible material has low heat value and meets other test criteria.

Building and fire codes often classify buildings by occupancy type. Some occupancies have concentrations of occupants. One classification is places of assembly, such as theaters, arenas, and auditoriums. Fire safety standards emphasize getting occupants out. Nursing homes and hospitals have special problems in getting immobile occupants out during a fire.

Other occupancies, such as manufacturing and storage buildings, may have flammable materials and items with high fuel loads. They pose different fire safety challenges in building design.

Another kind of classification involves the ability to retain structural integrity and provide fire barriers. Some classifications consider other features that limit fire and smoke movement within a building.

Structural Integrity

Many factors affect the ability of a building and the assemblies of materials in it to continue to carry loads during a fire. Designers use analytical design, data from design tables and guides, code requirements, and test results to reach decisions.

Materials expand when heated and contract when cooled. Different materials have different coefficients of

thermal expansion. If a design does not address potential expansion during a fire, structural damage may result from excessive loads that heated members place on each other. Steel structures often exhibit buckling and other failures from thermal expansion of members.

Temperature also affects the strength properties of many materials. For example, when heated, steel quickly loses its ability to carry a load. If temperatures are high enough, steel elements may not carry their own weight. Often steel elements have overlays of materials (plaster, gypsum, and other materials) that insulate them from the high fire temperatures.

Wood is a combustible material. However, depending on moisture content, it may not collapse rapidly due to the insulating effect that char provides. Treatment of wood and some other combustible materials with chemicals or finishes can slow the rate of burning.

Concrete is a common structural element. Although it has some insulating properties, heat can damage it, causing loss of strength, spalling, and other effects. The materials in concrete and mixing methods can affect the ability to withstand heat from fire. Heat reaching reinforcing materials in concrete can significantly reduce structural capacity.

Confinement

A major goal in building design is limiting a fire to the area of origin. Confining a fire to a small area is best. Some call this strategy *compartmentation*. Designs for a building and each portion of it should restrict horizontal and vertical movement of fire, smoke, and heat. Partitioning assemblies, doors, windows, duct runs and other openings should meet fire ratings. The confinement should function until a fire is extinguished or burns itself out. When confinement is the design criterion, potential fire severity determines what fire resistance to achieve. Fire resistance must allow time to exit and time for fire fighters to begin control and extinguishing actions.

Firestopping

In applying compartmentation during construction, much of the focus is on walls, floors, and other partition elements. The fire resistance ratings result from tests that determine the amount of time these elements confine a fire.

Recall that most fire-related fatalities result from smoke inhalation. That increases attention to other aspects of compartmentation. A significant problem involves gaps and holes in partitions. Smoke and potentially fire can move through the holes. There is a need to route heating and cooling ducts, pipe, electrical and communication conduits, and other items through walls, ceilings, and floors. Sometimes there are gaps between partition elements, such as along floors and ceilings.

Firestopping involves closing and plugging these penetrations. See Figure 16-5 for an illustration of some types of holes and gaps. There are a wide variety of devices for specific kinds and sizes of holes and gaps. Some of the devices and materials form *intumescent* fire seals. Intumescent materials swell when heated. They increase in volume and decrease in density. Some can reduce the rate of heat transfer. If there is a fire, intumescent materials can seal a hole or gap even tighter in the presence of heat than when first placed during construction.

Fire Spread

The goal of compartmentation is to confine a fire to the room or area of origin. Wall, floor, ceiling and opening barriers have ratings to help achieve that goal. When rated barriers are in place, fires do not spread readily by heat transfer or structural failure of the barriers. They spread primarily through horizontal and vertical openings, such as open doors and unenclosed stairs and shafts.

Many buildings have interstitial spaces between floors for electrical and communication lines, heating and cooling ducts, and steam and water lines. Fires in these hidden areas can burn for some time. When they break through a ceiling, for example, they can spread very rapidly across an open room. A flame front following breakthrough in a ceiling will often travel faster than occupants can run.

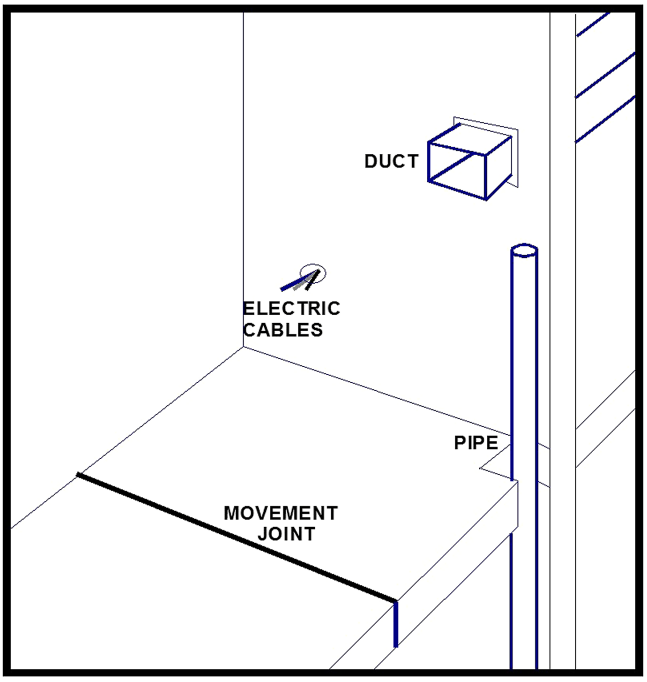


Figure 16-5. Examples of some common wall and floor penetrations requiring fire stop protection. There are many other kinds of penetrations beside those shown.

Vertical openings may exist between wall surface materials. Vertical shafts may house electrical, communication and other building services. Laundry chutes, elevator shafts, ventilation shafts, or atriums are all examples of vertical openings.

Preventing fire spread through horizontal and vertical openings in buildings may be difficult, but several approaches can reduce the rate of spreading. Where possible, concealed spaces should not have combustible materials. Like other spaces, they should have rated fire stop barriers. Fire-retardant coatings may help. Vertical openings should have blocking where possible. An example of blocking is placing cross-pieces between wall studs that are longer than 6–8 feet. Fire doors and shutters that close automatically when a restraining device get heated help prevent fire spread for larger openings of escalators and conveyors. Limiting fire spread in atriums requires a combination of design features.

Fire Load

Three stages characterize a fire: growth from a small origin, full development, and decay. In a fully developed fire, the temperature in a confined space will reach 1,500–2,300 °F. Before or during full fire development, the contents of a room may burst into flames. This phenomenon is called flashover.

The severity of a fire in terms of intensity and duration is a function of the quantity of combustibles available, their burning rate, and the air available for combustion. The surface area of fuel and the amount of oxygen control combustion. The greatest heat load occurs when there is just enough ventilation so the fuel surface area controls the rate of combustion. At low oxygen supply rates, ventilation limits the rate of combustion. High ventilation rates remove heat from the area of the fire, which reduces the heat transfer rate.

Plots of time and temperature provide a basis for assessing fire severity. The procedure compares fires with different temperature histories to standard time-temperature profiles. A test fire is equivalent in severity to the standard when the areas under the time-temperature curves are equal. Barriers, such as walls, floors, ceilings, and doors, must be able to withstand the desired fire severity.

Studies have shown a relationship between fire severity and fire load. One can estimate the fire load during design or use of a building. The result gives some idea of the severity potential. Fire load is the maximum heat released if all combustibles in a fire area burn. That includes heat from combustible contents and combustible interior finish, floor and structural materials. The usual expression for fire load is the equivalent combustible weight divided by the fire area, given in pounds per square foot. Actual fire loads are adjusted to the equivalent heat of combustion of ordinary combustibles, assumed to be 8,000 BTU/lb. Table 16-5 gives approximate heat of combustion data for some common materials.

TABLE 16-5 Approximate Heat of Combustion for Some Common Materials

Material	(MJ/kg)	(BTU/lb)
Charcoal	33.7–34.7	14,492–14,879
Coal		
anthracite	30.9–34.6	13,288–14,879
bituminous	24.7–36.3	10,621–15,610
Cotton	16.5–20.4	7,096–8,773
Gasoline	46.8	20,126
Kerosene	46.4	19,954
Leather	18.2–19.8	7,527–8,515
Oil, linseed	34.2–39.4	16,857–16,943
Paper		
brown	16.3–17.9	7,010–7,698
magazine	12.7	5,461
newsprint	21.5	9,246
Rubber-auto tires	32.6	14,019
Starch	17.6	7,569
Straw	15.6	6,708
Wheat	15	6,451
Wood		
birch	20	8,600
Douglas fir	21	9,031
maple	19.1	8,214
red oak	20.2	8,687
spruce	21.9	9,375
white pine	19.2	8,257
hardboard	19.9	8,558
Wool	20.8–26.6	8,945–11,439

Example 16-2 Assume that a warehouse contains 1,000 lb of epoxy stored in a 50 ft^2 area. What is the fire load? The heat of combustion of epoxy is about 14,400 BTU/lb. The fire load is $1{,}000\ lb \times 14{,}400\ BTU/lb / 8{,}000\ BTU/lb / 50\ ft^2 = 36\ lb/ft^2$.

When storing ordinary combustibles, such as paper, in steel containers, they will not burn completely and contribute the full heat value of the materials. Usually ordinary combustibles stored in partially and completely enclosed steel containers have derated values when estimating fire loads.

For fully enclosed containers, the ratio of fully enclosed combustible weight W_E to the total weight of all combustibles F_T determines what derating factor K to use:

W_E/F_T	K
< 0.5	0.4
0.5–0.8	0.2
> 0.8	0.1

For containers that have one side open (partially enclosed), the weight of ordinary combustibles W_P is derated by $K = 0.75$.

CASE 16-3

16-3a

October 1983, Rhinehart, VA. A tire storage facility with about 7 million tires caught fire. It created a smoke plume about 3,000 feet high and 50 miles long. It caused pollution in three states. The fire burned for 9 months. It became a Superfund site and cleanup work finished in 2002.

16-3b

September 22, 1999, Westley, CA. Lightning struck and ignited a tire dump containing about 7 million tires located in a coastal canyon. The fire produced pyrolitic oil that flowed into a stream. It, too, caught fire. Local and state fire organizations could not handle the fire. The Environmental Protection Agency took over the extinguishment, which took a month and cost $3.5 million.

Collection and processing of old tires have created many, difficult-to-extinguish fires. One of the problems is the concentration of combustible material. The fuel load builds up and regular fire equipment does not have the capability to handle extinguishment.[a,b,c]

[a] www.epa.gov/osw/conserve/materials/tires/fires.htm
[b] http://webecoist.momtastic.com/2013/05/28/burn-rubber-the-worlds-9-worst-tire-fires/
[c] http://articles.chicagotribune.com/1988-01-13/features/8803210990_1_oxford-energy-tires-rubber-is

The total derated fire load F_L is the sum of combustibles in the open, derated fully-enclosed combustibles and derated partially-enclosed combustibles.

16-6 INDUSTRIAL AND PROCESS FIRE HAZARDS

General

In many ways the fire hazards in industrial facilities are the same as in other facilities. One major difference is the quantity of materials, fuels, and power present in one location. Each kind of operation and process presents particular fire prevention and protection problems. This text cannot discuss in detail each operation, process and kind of material. A few operations, principles and procedures give examples. One should consult specific references to find out more about particular fire hazards and controls.

Venting

One problem found across many industries and processes is the use of single-story facilities. As noted earlier, heat and smoke can move rapidly under the roof of a horizontal building. There are some techniques that can help confine fires in industrial plants. Ventilation is an important method. Roof vents allow hot gases to escape and do have some effect on confinement.

Compartmentation will help limit the horizontal spread of fire. In industrial plants full partitions may interfere with the flow of materials and production activities. Where operations require large open spaces for manufacturing and material handling processes, partial partitions may hang from the ceiling. Curtain boards are vertical panels constructed of noncombustible materials and suspended from the ceiling. When they fit tightly to the ceiling and extended as far to the floor as possible, they can prevent the lateral movement of hot gas layers. In effect, curtain boards can partition a large plant into smaller areas to control fire spread. Figure 16-6 illustrates the use of curtain boards.

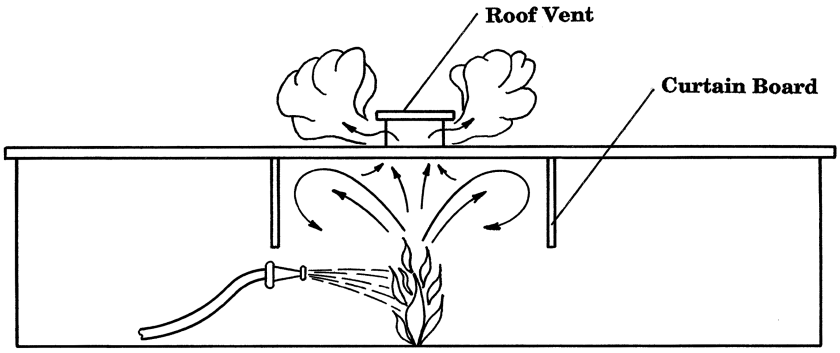


Figure 16-6. Example of curtain boards for limiting fire spread in horizontal construction.

There is a need to provide vents within each area or section created by curtain boards. From knowledge of fire behavior and the development of a hot gas layer below a ceiling, an expression for the amount of vent area A required for a section is

$$A = 0.14\,ph^{3/2}/d^{1/2} \qquad (16\text{-}4)$$

where

A is the vent area required in square feet
p is the perimeter of the fire area in feet
h is the distance from the floor to the base of the hot gas layer in feet
d is the depth of the layer in feet

Example 16-3 In a factory the curtain boards hang 10 ft from the ceiling. The bottoms of the curtain boards are 14 ft from the floor. The fire itself occurs within a 4 ft × 5 ft area. Assume that the hot gas layer formed along the ceiling extends half the distance to the bottom of the curtain boards, how much vent area is needed?

The perimeter of the fire is $(2)(4+5) = 18$ ft. Then, applying Equation (16-4),

$$A = 0.14(18)(14+5)^{3/2}/5^{1/2} = 93.3\ \text{ft}^2$$

Fire Walls

Another way to prevent lateral spread of fire in large buildings or between buildings is by using fire walls. Fire walls must withstand potential complete burnout on both sides. They require special structural construction so heat and collapse of other building components will not affect their stability. One can often visually identify fire walls from outside a building. They usually have a parapet extending about 3 ft above the roof line. The parapet helps prevent fire from burning along the roof and across the fire wall. Fire walls have some limitations and other partitioning methods may be preferable.

Welding and Cutting

Common industrial processes are welding and cutting. Unsafe welding and cutting procedures and equipment too often lead to fires. There are other hazards for welding and cutting. Heating certain materials with welding equipment may produce toxic gases and vapors. Welding processes can also damage eyes. Later chapters discuss these hazards. One should also reference special publications on welding and cutting equipment and operations that provide more details on hazards and controls.

The main types of welding are electric welding and oxygen-fuel welding. The most common form of electric welding is arc welding. An arc passes between the metal to be welded and an electrode. There are several kinds of electrodes, some containing the filler material for the joint. The electric arc creates a high, localized temperature that melts the filler material and heats the surrounding metal. There are several variations to the basic arc welding process for different metals and for improved control in automated welding.

In oxygen-fuel welding, a fuel (the most common fuel is acetylene) mixes with oxygen in a nozzle device or torch. Both oxygen and fuel move from separate compressed gas tanks through pipes and hoses to the torch. When ignited, the operator adjusts the rate of fuel to achieve very high temperatures that heat the metals being joined and the filler material to form a bond.

Variations of arc and gas welding processes allow one to cut metals. The processes cut through a narrow band of metal. High temperature and open flame equipment involved in welding and cutting create fire hazards. There is scattering of sparks and hot metal particles. The objects worked on and the work area may ignite. Sparks and hot particles fly from the operation and may fall to lower locations or into cracks and openings. The sparks and hot particles can travel as far as 30–50 ft. They can ignite flammable and combustible material within such an area.

Because persons doing welding wear high density glasses or face shields to protect eyes from the intense light, they cannot see what is going on in lower light levels. They have difficulty monitoring their work area. When the welding operation is unconfined or performed in an unsafe location with combustibles, the operation needs a fire watcher. The fire watcher's job is to monitor the area around the operation for lingering sparks or fire and extinguish them. Case 16-1 illustrates the consequences of inadequate management of a welding operation.

Welding equipment needs special care to prevent accidental operation. Users must handle and maintain the oxygen supply carefully and properly. Leaking oxygen could get into clothing and other material and cause rapid flame-up if ignited. Electrical equipment requires grounding, All electrical equipment should comply with electric codes. Users must keep cylinder valves closed when not in use. Leaking fuels, such as acetylene and butane, can lead to explosions.

The objects worked on and the environment need proper controls as well. A common problem is repair of a container that had a fuel in it. The vapors can ignite and explode and result in severe injury or death. To prevent such events, containers need to be cleaned and flushed out to remove residual fuel. Another method is filling such containers with water or sand during welding. That fills the tank so there are no remaining vapors.

The environments for welding and cutting must be free of flammable gases. In confined spaces there is a need to provide adequate ventilation and breathing air. Welders must wear proper protective clothing. Welders and others involved

in welding and cutting operations must have training in safe operations and hazard recognition and proper controls.

Hot Work Permit Procedures

Many organizations use a permit procedure for all hot work that is not part of normal operations or processes. Hot work is any kind of welding, cutting, burning, or activity that involves or generates sparks or open flame. It includes heated equipment that might provide an ignition source for a fire. Hot work often involves people from a maintenance department going to other departments to perform activities. The main idea in a hot work permit procedure is to gain the participation of all individuals and supervisors involved in any way to make the work safe. Normally there is a permit requiring individuals and supervisors to agree and sign that safe equipment and procedures are in place before work begins. The concept implies that each person signing the permit has reviewed the work setup, equipment, and procedures for the work and agrees that it is safe to proceed with the work. The potential weakness of the procedure is that someone may not have completed a review and simply signs the document. Figure 16-7 is a sample hot work permit and procedure summary.

General Storage

Storage of flammables and combustibles requires special attention. This discussion covers a few basic storage principles. However, applicable sections of the National Fire Code[9] have greater details for particular storage matters focused on fire protection.

Indoor Storage of Flammable Liquids

Many operations use flammable liquids. Examples are cleaning, fuel for equipment and other purposes. To prevent fires,

PERMIT
Cutting and Welding
with Portable Gas or Arc Equipment

Date _____ Building _____

Dept _____ Floor _____

Work to be completed _____

_____

Special precautions to be taken _____

_____

Fire watch required? ☐ Yes ☐ No

I have examined the location where this work is to be performed, identified the necessary precautions, and therefore grant permission for this work as show on the reverse side of this permit.

Permit expires _____

Signature _____
(Person responsible for authorizing welding and cutting work.)

Time and Date: Work started _____

Completed _____

FINAL CHECK-UP

I have inspected the work area and all surrounding areas for sparks and heat (including floors above and below, opposite sides of walls, and enclosed areas) at least 30 minutes after the work was completed and found no signs of combustion.

Signed _____
(Supervisor or Fire Watcher)

PROCEDURE SUMMARY

Before approving any cutting and welding permit, the fire safety supervisor or his appointed alternate shall inspect the work area and confirm that all necessary precautions have been taken to prevent fire in accordance with NFPA standards and company policy.

PRECAUTIONS
☐ Sprinklers in service
☐ Cutting and welding equipment is in good repair

WITHIN 35 FEET OF WORK
☐ Floors are swept clean of combustibles
☐ Combustible floors are wet down, covered with damp sand, metal or other shields
☐ No combustible material or flammable liquids are present
☐ Combustibles and flammable liquids are protected with covers, guards, or metal shields
☐ All wall and floor openings are covered
☐ Covers are suspended beneath work to collect sparks

WORK ON WALLS OR CEILINGS
☐ Construction is noncombustible and without combustible covering
☐ Combustibles are moved away from opposite side of wall(s)

WORK ON ENCLOSED EQUIPMENT
(Tanks, containers, ducts, dust collectors, etc.)
☐ Equipment is cleaned of all combustibles
☐ Containers are purged of flammable vapors

FIRE WATCH
☐ To be provided during and for 30 minutes after operation
☐ To be supplied with extinguisher and small hose
☐ Fire watcher is trained in use of equipment and in sounding fire alarm

FINAL CHECK-UP
☐ To be made 30 minutes after completion of any operation unless fire watch is provided

Signed _____
(Supervisor)

Figure 16-7. An example of a hot work permit form.

there are many requirements for storage and dispensing of flammable liquids indoors. One general principle is to limit the quantity of flammables stored in an occupied or operational area to those that are needed for specific jobs or a single day. Larger quantities should have special storage facilities that are separate from occupied and operational areas.

Storerooms Special storerooms confine flammable liquids. NFPA has detailed design standards for these storerooms. Fire codes limit the quantities and sizes of containers stored indoors. Some design features for flammable storerooms are explosion-proof switches and electrical fixtures, ventilation, self-closing doors with fusible links, static electricity grounding systems, special signage, raised door sill, and special floor contours.

Storage Cabinets Storage cabinets may be located outside special storerooms. Standards and codes specify their design and construction and limit the quantities of flammables they may contain. Cabinets help protect stored liquids from fires outside them, confine spills within them and keep flammables organized. There are also various styles of safety cans and vertical or horizontal dispensing drums.

Grounding and Bonding When transferring flammables from storage drums to small dispensing containers or when there are transfers of large quantities of flammables, there must be a connection between containers with an electrical conductor (bonding). Or both must have connections to a grounding rod or line. (See Chapter 12 for a discussion of bonding and grounding.)

Drums Store flammable liquids in closed containers or drums. Dispense flammable liquids from drums by gravity or suction pump, not by pressurizing the drum. Valves for gravity dispensing must have recognized testing laboratory approval and close automatically. There must be drip containers to catch leaking fluids.

Safety Cans Safety cans contain 5 gallons or less of flammable liquids. They are intended for moving fluid to the point of use. They have several safety features. The spout caps close automatically after tilting or pouring. They have a pressure relief valve to vent vapor. They have a flame arrester in the spout. In the event of a flame on the outside, the arrester absorbs heat and prevents the flame from passing to the inside of the can. Safety cans have leak-resistant designs.

Plunger Cans Plunger cans wet cleaning cloths or wipes with flammable liquid. A shallow pan rests on the end of a shaft that is spring supported on the top of the can. By placing a cloth or wipe on the pan and pressing down, a small amount of fluid pumps into the cloth through the dispensing shaft. Excess fluid drains back into the can.

Cleaning and Dip Tanks There are many fire protection features for cleaning and dip tanks. Tanks vary in size and capacity, and design features. They have covers that protect the fluid from ignition in a fire. Some have foot-operated lids that close when no one is stepping on the lever that opens the lid. Others are normally open and have fusible links that melt at relatively low temperatures, causing the lid to close. Some have drain boards that allow washed parts to drain excess fluid back into the tank. Additional protection for large tanks includes sprinklers and automatic drains. In the event of a fire, the fluid drains to a holding tank. Some cleaning and dip tanks have other fire extinguishing equipment.

Waste There are self-closing containers for storing cloths and wipes contaminated with flammable liquids. Waste containers are small to limit the accumulated quantity. Waste containers must be emptied regularly so containers do not overflow. A foot lever opens a lid. The lid closes when a user releases the lever. Other design features prevent heat transfer to the contents.

Warehouses and Other Facilities

There are many fire protection problems in warehouses. One should refer to the NFPA *National Fire Code* and other sources for more details about storing particular materials and fire protection in warehouses. Fire protection consideration includes type of commodity, ease of ignition, rate of fire spread, and rate of heat produced. Other factors are quantities of material stored, how they are stored, height of storage, and accessibility. Distance to other commodities can also be important. For example, fuels must be separate from oxidizers. All these characteristics help determine the fire hazards and suitable designs and controls.

For warehouse storage, codes group commodities that have similar fire hazard and control characteristics into classes. Standards specify the storage height for commodity piles because the height of materials affects fire growth, intensity, and control.

Because some warehouses have high densities of flammable and combustible materials, there should be a combination of extinguishing equipment. Sprinklers are essential. Water from sprinklers may not reach fires between, under or within units of stored materials. To deal with those deficiencies, there is a need for fire hoses and portable extinguishers. It may be necessary to move some materials to gain access to burning units. Sprinkler design standards mandate clearances between stacked material and sprinkler heads to allow spray patterns to develop. Standards also give flow rates, sprinkler head density, temperature ratings of sprinkler heads, water flow rates of auxiliary fire hose, overall water supply, and other requirements for various commodities and classes of commodities. Type of storage also affects sprinkler system requirements. Examples are storage on

pallets, in boxes and bins, on racks, in bulk, or in packaged units. Requirements vary somewhat for different types of facilities, such as indoor versus outdoor, cold storage, bulk tanks, or bins.

16-7 LIFE SAFETY

Protection of human life is the first priority in a fire. Life safety in a facility provides occupants with (a) a reasonable degree of safety from fire, and (b) an adequate opportunity to exit if a fire occurs. There are many codes and standards adopted by organizations and government units to achieve life safety. The most often cited life safety standard is NFPA 101.[10] NFPA also provides explanations for the theories or concepts behind particular elements in the standard.[11]

Human Behavior in Fires

Under the stress of a fire situation, people do not always behave logically. The behavior of one person may affect the behavior of others. Incomplete information about fire conditions and exit routes during a fire confound personal behavior. Individual conditions affect by fire behavior. Examples are age, mobility, ability to see and hear, and previous training. Physical conditions in a fire, such as smoke, loss of power for lights, rate of fire spread, and heat buildup, affect visibility, options for movement, and decision-making. Density of people, the number of exit routes, capacity of routes and distance to the exterior affect movement and travel time. Today, computer modeling systems allow designers to model exiting behavior with some degree of precision and evaluate some building features related to life safety.[12]

General Principles of Life Safety

The degree of fire hazard for a building determines the risk to occupants. The degree of fire hazard depends on building contents, the rate of fire propagation for the contents and activities performed in a building. Life safety codes recognize three classes of hazard: low, ordinary, and high. Life safety codes also divide regulations by type of occupancy. Examples are residential, places of assembly, hospitals, and industrial.

Provisions of life safety codes address many aspects of a building. There are properties of interior finishes, size, number and location of exits, exit distance, protection of exit routes from fire and smoke, alarm systems, emergency lighting, signage for exit routes, compartmentation, construction type, horizontal and vertical openings, extinguishing systems, and other factors. The discussion below addresses some of these provisions. For details, refer to the standards.

Interior Finishes

Interior finishes are the materials that make up exposed interior walls, column and ceiling surfaces in buildings. Interior floor finishes refer to the floor covering. Testing laboratories evaluate finish materials for two fire characteristics. The first is how quickly flame spreads across the material. The second is the amount of smoke produced. There are three classes for interior finishes: Class A, B, or C. Controlled laboratory tests determine ratings of the materials. For example, ratings by class are:

1. Class A–flame spread 0–25; smoke developed 0–450
2. Class B–flame spread 26–75; smoke developed 0–450
3. Class C–flame spread 76–200; smoke developed 0–450

For floor finishes, there are two classes: Class I and Class II. Controlled laboratory tests depend on critical radiant heat flux ratings.

The codes specify the classes of finishes allowed for each occupancy and specify surfaces for exits, access to exits and other spaces.

Egress

Many factors affect the ability to egress and the time required to exit. Means of egress is the path of travel from any point in a building to the open air outside at ground level. There are three parts to means of egress: exit access, exit, and exit discharge.

Exit access is a path leading to the entrance to an exit.

An *exit* is a protected zone of a building that leads outdoors at ground level. It may consist of doorways, stairs, ramps, corridors. or fire escapes bounded by walls, floors, and doors. An exit is bounded by one or more entrances to it and one or more doors to leave it at ground level.

Where doors leaving the exit do not open directly to the outside ground, an *exit discharge* is the last segment between the protected exit and the outside ground. An exit discharge may be a short entryway, stairs or hallway open to the outside, but separated from an exit.

Exit and Exit Units The unit of measure for an exit is the *exit unit*. One exit unit is 22 in. wide, the average width of a person at shoulder height. Exit widths are normally expressed in whole exit units; sometimes in half units. For example, an exit corridor 48 in. wide is 2 exit units. Partial exit units equal to or greater than 12 inches are half exit units. An exit corridor 58 inches wide would be 2½ exit units.

Access to an Exit Occupants should be able to travel to an exit without obstructions. Designs should avoid dead ends. Standards set travel distance limits to an exit. Routes should not require passage through lockable doors (see Case 16-4) and should not pass through areas of severe fire hazard. Maximum travel distance permitted from any point to an exit

CASE 16-4

September 3, 1991,Hamlet, NC. Shortly after the morning work shift began at the Imperial Foods Processing Plant, a fire broke out in the 30,000 sq ft building. The plant processed poultry. A hydraulic line near a cooker ruptured and sprayed hydraulic fluid. The fluid ignited. The fire spread rapidly and created heavy black smoke containing toxic gases throughout the building. Workers scrambled to escape. Workers found several exit doors locked. Some sought refuge in a cooler. There were 25 fatalities and 54 people received injuries.[a]

[a]www.usfa.fema.gov/downloads/pdf/publications/tr-057.pdf

varies with occupancy and whether the building has a sprinkler system. Minimum corridor widths vary with occupancy, but are generally 36 in. or more. A 44 inch corridor would be 2 exit units wide. If access involves use of stairs, the stairs must meet design standards.

Exit Capacity Life safety standards give capacities for exits. The capacities vary with occupancy, which adjusts all occupancies to a similar total exiting time. The standards also vary for stairs, ramps, doors, horizontal exits, and escalators. The number of exit units affects capacities required for an occupancy.

Occupant Load Occupant load is the number of people expected to be present at one time in a building (or floor). The standards set minimum occupant loads, usually expressed as square feet per person, when estimating the number of occupants. Other units are inches per person for bleachers and other bench-type seats and number of fixed seats. The standards vary with occupancy.

Number of Exits One principle of exit design is providing at least two routes of egress from any point in a building. Certain occupancies and occupant loads require more exits.

Exit Routes Building exit routes should be in opposite directions as much as possible. This allows people to exit away from a fire and to avoid passing through a burning area. In places of assembly there must be aisles and cross-aisles. The standards specify the number of aisles and aisle widths and the maximum number of seats a person can be from an aisle.

Stairs Standards specify various characteristics of stairs. Included are clear width, tread and riser dimensions, head room, distance between landings, and landing dimensions. There are also winder, spiral and curved stair specifications. There are other details about stairs including handrails, guardrails, stairs enclosures, and other features.

Doors Doors that are in the routes of exit must have hinges, must swing in the direction of people's movement and must open fully. Where doors swing into a corridor, aisle, or passageway, they must not impede movement. Recessed areas for door swings are one solution. Specifications govern door width, type of door, floor conditions near doors, and other details.

Hardware The codes detail lock and latch hardware. Sometimes building security and safe egress may appear to be conflicting, but the code covers acceptable solutions to such conflicts. See Case 16-4.

Lighting Visibility is important in exiting a fire. Not only can smoke build up rapidly and obscure vision, but there may be a power interruption to building interiors. Loss of normal lighting is particularly a problem for buildings with few or no windows. The code specifies details for emergency lighting systems, which require routine maintenance to ensure they work when needed.

Signs Finding the exit routes in a building is essential to safe egress. The code specifies signs and sign placement. Signage not only tells the routes of exit, but gives warnings about blocking and locking exit doors.

Detection, Alarm, and Communication Systems Occupants of a building must know when to begin exiting. After detecting a fire, there must be an alarm to alert occupants. In some cases, an alarm must issue particular instructions. Then people must begin to move toward and out exits. The code gives specifications for these systems. More recent systems can issue verbal instructions.

Other Factors Life safety standards address many other details about construction of exit enclosures, building services, and equipment. Specifications may vary for different occupancies and hazards.

Exit Design

In life safety design one must compute the required number of exit units. The procedure involves computing the occupant load for a floor and then the number of exit units.

$$\text{Occupant load} = \text{floor area}/\text{allowable occupant load} \quad (16\text{-}5)$$

$$\text{Number of exit units} = \text{occupant load}/\text{allowable capacity per exit unit} \quad (16\text{-}6)$$

The floor area comes from the building floor plan. Codes specify the allowable occupant load and allowable capacity per exit unit for particular occupancies.

Designers must apply this procedure to each floor and to the entire building. Exits serving more than one floor are not based on the addition of exit units from all floors, only the floor with the highest required number of exit units.

16-8 FIRE DETECTION AND ALARM SYSTEMS

Fire Protection

Fire protection refers to methods for controlling and extinguishing fires. It involves working against time. Figure 16-8 illustrates the process. Indicators of combustion are smoke, flame, and heat, so systems must detect any of these in some manner. Then systems must warn occupants so actions to preserve life and property can begin. The actions include exiting or getting people to safety and fighting the fire. The fire fighting goals include minimizing the amount of property involved and extinguishing the fire.

Fire Detection and Alarms

There are many kinds of equipment for detecting fires and giving alarms. The devices may be quite simple, applying only to certain aspects of the process. Devices may depend on human activation or be automatic. The devices can combine several functions into sophisticated sensor, annunciator, and alarm systems. Systems require regular testing to ensure that components work properly. Systems today are likely to have computer controls. The computer may constantly perform internal checks for component failures and report which ones do not work properly. Several NFPA codes establish standards for sensor and alarm components and systems.

There are several kinds of detectors. There are detectors for heat, smoke, flame, and gas content. Each type works best for particular applications. Selection depends on the type of fire that can occur and the kind of flammable or combustible materials present. Placement of detectors is critical. Some require more maintenance than others. Routine testing is essential to assure reliable performance.

Heat Detectors There are several kinds of heat detectors. They include fixed temperature detectors, rate-of-rise detectors, rate compensation detectors, and others.

Fixed Temperature Fixed temperature heat sensors operate when a sensor reaches a preset temperature. They are a variety of temperature settings. Because there is some mass in the sensors themselves, the fixed temperature sensors take some time to respond to conditions. The air surrounding the device will reach the trigger temperature at some time before the sensor elements do. The time lag depends on the device. Because of the lag, fixed temperature sensors are not suitable for fires that develop quickly.

Many fixed temperature sensors depend on fusible elements made from metal that melts at a preset temperature. The break in an element may couple mechanically or electrically to other actions, such as turning on sprinkler heads or an alarm system.

Another type of fixed temperature element uses two continuous wires, separated by insulation. When the sensor reaches a predetermined temperature, the insulation melts and the wires come into contact. The contact activates electrical circuits.

A third type of fixed temperature element uses bimetallic strips or disks. The two metals forming the strip or disk each expand at different rates with temperature increases. This causes the strip to bend or the disk to snap to a different curvature. The movement couples to electrical circuits.

Rate of Rise Rate-of-rise detectors respond to fires that flame up quickly. They do not react well to slower changes in ambient temperature expected for slow developing fires. They typically respond to temperature changes on the order of 12 °F/min.

One design involves two physical phenomena. First, the air inside a tube expands and builds up pressure inside the tube. When the pressure reaches some predetermined level, a switch closes or opens.

The second function involves a tube with a small hole in it that allows expanded air to leak at a controlled rate. The difference between these two phenomena measures the rate of temperature rise.

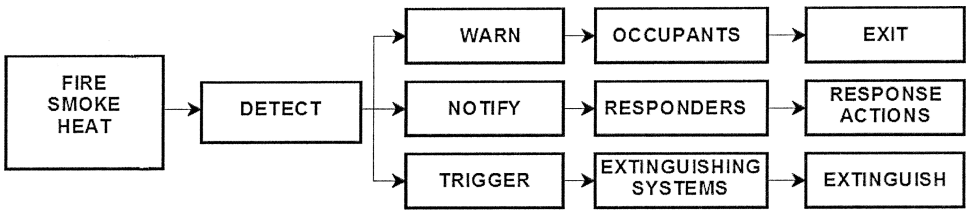


Figure 16-8. Typical actions in response to a fire.

Rate Compensation A rate compensation detector responds to a preset temperature. However, it is less sensitive to thermal lag than a fixed temperature device. The sensor will detect the present temperature increasing rapidly and trigger the action when reaching the preset temperature.

Other Other heat detectors use thermocouples and release of gas from solids to sense temperature changes and trigger switches and controls. In addition, some detectors have multiple elements that respond to both rapidly and slowly developing fires.

Smoke Detectors In many fires there is smoke before there is any significant heat buildup. As a result, smoke detectors will usually detect fire before heat sensors. Smoke detectors operate on one of two principles: ionization or photoelectricity.

Ionization Ionization detectors contain a very small quantity of radioactive material. They ionize the zone of air around the radioactive material, making the air conductive. When smoke particles enter the zone, the conductivity decreases. An electrical circuit that monitors the conductivity can detect the conductivity decrease and trigger an alarm. Ionization detectors are most sensitive to small smoke particles found in high energy, open flame fires.

Photoelectricity Photoelectric smoke detectors depend on a source and receiver of light. There is a beam from the light source to the receiver or sensor. Smoke particles entering the beam reduce the light arriving at the sensor and scatter the light of the beam. A receiver positioned in the beam detects the reduction in light when smoke is present. The reduction triggers an alarm. For a receiver located outside the normal beam, the scattered light will fall on the sensor. When sufficient light arrives at the sensor, it triggers an alarm.

In some types of photoelectric detectors, a vacuum pump draws air from one or more locations to a central sensing device. Any of the sources can trigger a response from the sensor.

Flame Detectors Flame detectors monitor for certain wavelengths in the field of view of the sensing device. Infrared and ultraviolet wavelengths are most common. These devices sense the glow from flames or embers. Some infrared sensors monitor a wide band of wavelengths. Others measure frequency of infrared present in its field of view, such as that from a flickering flame. Broadband infrared sensors may have false readings from sunlight or other radiant sources that are not sources of fire. In such cases the detector must have shielding from alternate light sources. Such detectors require judicious use because a shielded flame detector may not see the fire source. It cannot respond.

Gas Sensors These detectors sense the presence of certain gases produced by combustion in most fires. Electrical circuits coupled to sensing devices trigger alarms.

Alarms and Controls There are many kinds of alarm and control devices activated directly or indirectly from detectors or manual signaling devices. Alarms may be auditory or visual. Visual alarms may simply be a light on an annunciator panel located at the entrance to a building or at some central monitoring station. Audio alarms may have continuous or intermittent tones, variable pitch tones or voice instructions. Alarms may activate fire and smoke control doors or hatches, may unlock security systems and may affect elevator controls or heating, ventilating, and air conditioning (HVAC) equipment. Voice communication may be live instructions from a central station or recorded messages from recordings or computer chips. Each application dictates the kind of alarms and controls needed.

16-9 FIRE EXTINGUISHMENT

Fire extinguishment is the application of agents to control fire spread and ultimately to put a fire out. By far water is the most common agent. For some applications, water additives enhance the capabilities of water. Other agents are carbon dioxide, halogens, dry chemicals, foams, and other special purpose agents.

Kinds of Extinguishment

Fire is extinguished by eliminating any or all of the four components that make up the fire triangle and the fire pyramid. For most materials, combustion will stop with the removal of heat, fuel or oxygen. In addition, combustion will no longer occur if there is an interruption in the creation of the hydroxyl radical.

Portable Fire Extinguishers

Most fires start in a small way. Extinguishment is easiest during their early stages. Portable fire extinguishers contain small quantities (for ease of carrying and handling) of extinguishing agent suitable for the suppression of small fires. Extinguishers need strategic locations for quick response. They must suit the kind of fire encountered and work properly. The user must know how to use them correctly. There are extinguishers with various kinds of extinguishing agents. There is an NFPA standard for portable fire extinguishers.[13]

Classes of Fires There are four classes of fires. The classification scheme helps determine suitable agents in extinguishers for different fires.

Class A This class covers ordinary combustibles (wood, paper, cloth, rubber, plastics). Extinguishment results from cooling or smothering.

Class B These fires involve flammable and combustible liquids, flammable gases, greases, and oils. Extinguishment involves inhibiting the release of combustible vapors or the development of the hydroxyl radical.

Class C This class addresses electrical equipment fires. Extinguishing agents for electrical fires must not conduct electricity.

Class D This class covers combustible metals. Extinguishing agents must absorb heat and not react with the metals.

Portable Extinguishers Extinguishers may contain agents effective for one or more classes of fires. Labels on extinguishers identify the classes covered. Extinguisher labels also contain information about the effectiveness of the extinguisher. A label may read 4-A and 20-B. 20 indicates it is more effective for a Class B fire than for a Class A fire. These ratings only give relative effectiveness and are not absolute ratings. The 20 is not 5 times more effective than the 4 rating. An extinguishing agent may have ratings for more than one class of fire and each rating may differ in effectiveness.

Extinguisher Requirements Portable extinguishers do not replace fixed extinguishing systems. Standards define the number and distribution of extinguishers. Important considerations are the class of fire anticipated, the occupancy classification, the hazard class (light, ordinary, high) in the building, the floor area served, and the travel distance from any location to an extinguisher.

Extinguishers require inspection, maintenance, testing, and record keeping. Standards detail frequencies and procedures for these activities.

Water Extinguishment

Water can cool the burning surface of many materials and stop vaporization of the material necessary to support combustion. Through a change of state from liquid to vapor, water takes up much heat. Water can also extinguish some materials by smothering the fuel and preventing air from reaching it. However, because of danger from electric shock, water is not suitable for electrical fires. Also, water may react with certain materials and create hazardous chemicals or conditions.

Additives improve the effectiveness of water as an extinguishing agent for certain fire conditions. They may affect viscosity and surface tension, may cause foaming or create other characteristics, and may prevent freezing.

Water Supplies

Engineering of water supplies for fire protection is critical. Designs must consider the total amount available, the rate of supply at various locations, and the distribution system. Fire protection standards detail water supply requirements for fire protection in communities and special facilities. Standards also cover hydrants, pumps, fire hose, nozzles, and other components of water supply systems.

Chapter 10 discussed some hydraulics. Bernoulli's equation is an essential engineering principle in fire hydraulics. Losses in pipes, fittings, and other components are adjusted to equivalent pipe length for use in Bernoulli's equation. Distribution systems need regular testing to ensure availability of water supplies when and where needed.

Sprinkler Systems

Sprinkler systems are automatic or semiautomatic extinguishing systems for buildings and other facilities. Studies and experience have shown them to be the most effective means for controlling fires in buildings. Fires in most buildings with sprinkler systems require activation of only a few sprinklers near the fire for control. The cost to include sprinkler systems is offset by reduced insurance premiums and reduced losses if a fire does occur. There are standards for sprinkler systems.[14]

In general, sprinkler systems distribute extinguishing agents to the locations where fires occurs. Sprinkler heads operate independently and determine when they should release the extinguishing agent. Placement of sprinkler heads, type of head, appropriate agent, and proper maintenance and testing are essential to the success of a system.

Kinds of Sprinkler Systems There are many kinds of sprinkler systems. Most are water-based. However, some may have other agents.

Wet-Pipe Systems A wet-pipe system contains water under pressure at all times. Any sprinkler head that opens will allow water to pass immediately. Wet-pipe systems are subject to damage by water freezing in the pipes. Storing antifreeze solution in unprotected portions of the piping can prevent this threat.

Dry-Pipe Systems A dry-pipe system contains air or nitrogen under pressure at all times. A valve separates water supplies from the dry pipes. An open head will reduce the pressure in the gas-charged pipes and allow the valve to open, releasing water to the open sprinkler head and the fire. Dry-pipe systems are suitable for areas subject to freezing. Compared to wet-pipe systems, dry-pipe systems respond slower to a demand for water at a sprinkler head and more heads are likely to open in a fire. Special features prevent inadvertent operation of the water valve.

Preaction Systems This is a special form of dry-pipe system. The piping may or may not be under pressure. There are sensors in protected areas besides sensors at each sprinkler head. The special sensors detect a fire and open a valve to fill the pipe with water. The special sensors operate before those in the sprinkler heads. This design reduces the delay found in a dry-pipe system.

Combined Systems These systems combine features of a dry-pipe system and a preaction system. Pipes are filled with air under pressure. Supplementary sensors open a water valve and air exhaust ports. This allows the piping to fill completely with water before the sprinklers open.

Deluge Systems A deluge system is similar to a preaction system. All sprinklers are open at all times. Fire-detecting devices activate the water valve, allowing water to emerge from all sprinkler heads.

Other Systems Some systems have limited water supply locations. Special systems have one or more limited capacity pressure tanks to supply water. Some systems produce a water curtain to protect outside walls. Other systems provide targeted protection. An example is fixed water spray protection to provide cooling for tanks exposed to fire.

Components The main components of a sprinkler system are piping, sprinkler heads, and hangers. Piping distributes water throughout the system. Its main components are risers (major vertical pipes), cross-mains, and branches. Hangers of various types support the components. The branches extend from the cross-mains and sprinkler heads attach to branches. There are many kinds of sprinkler heads. Their features can affect how quickly they open, the spray pattern and distribution of water. Fusible links activate most sprinkler heads. The sprinkler code (see note 12) contains standards for all system components.

Sprinkler System Design

There are two methods for designing sprinkler systems. One is hydraulic design. The other works from tables, charts, and data provided in the code. The code specifies the water pressure required at each head. Achieving those pressures at each head will ensure the proper water flow rate at the heads. Selection of sprinkler heads helps get the water where needed and makes sure all areas or locations have protection.

Hydraulic Design In hydraulic design, calculations must show that a system achieves head pressures at all heads when water at some pressure and flow rate enters the system inlet. Hydraulic designs will usually reduce system components and costs compared to the table method. Computer programs help analyze sprinkler designs to determine whether they meet hydraulic requirements. The programs also simulate performance. The general formula in hydraulic sprinkler design is

$$P_i \geq P_s + P_f + 0.434h \qquad (16\text{-}7)$$

where

- P_i is the pressure at the system inlet (psi)
- P_s is the pressure at the sprinkler head of interest (psi)
- P_f is the friction loss from pipe length, bends, valves and other fittings (psi)
- h is the vertical rise from inlet to sprinkler head (feet)

Table Method Tables, charts and other data in the code define pipe sizes, the number of branches on a cross-main and the number of sprinkler heads on any branch. They also specify the maximum distance between sprinkler heads and between a sprinkler head and a wall. Tables state the maximum distance between branches and the maximum area any one head may serve.

Criteria differ by type of hazard. The table method involves a trial and error approach. The final design determines the minimum number of sprinkler heads and other elements necessary to tabular standards.

Fire Suppression Systems

Suppression systems that do not use water or modify properties of water work for particular applications. One should refer to applicable standards for design and use of these systems and agents. The agents are carbon dioxide, halons, dry chemicals, foams, and combustible metal agents.

Carbon Dioxide Carbon dioxide extinguishing systems store carbon dioxide gas or liquid under pressure. It extinguishes by reducing the oxygen content of air and by cooling. It is most suitable for Class B fires. It has its uses, but is less effective, for Class A fires. It can be toxic. It has a noisy discharge. In enclosed spaces it can reduce the oxygen content for breathing. Carbon dioxide can be piped from storage containers to points of application. Application occurs by filling an entire enclosure (total flooding) or by local application to burning material.

Halons Halons are hydrocarbons in which atoms from halogens replace one or more hydrogen atoms. Halons include fluorine, chlorine, bromine, or iodine. There are a variety of halon systems. Extinguishing involves interruption of the hydroxyl radical of combustion. Some systems are discontinued because of toxicity and corrosion effects. Today two halons are in general use: Halon 1211 (bromochlorodifluoromethane) and Halon 1301 (bromotrifluoromethane). Effectiveness is a function of many factors. Halon 1301 is best suited for total flooding applications, whereas Halon 1211 is well suited for local application systems. Halon

systems deliver extinguishing agents under pressure with nitrogen. Low concentrations appear to have little toxic effect on humans, but do contribute to environmental problems (ozone depletion). The design of Halon systems must include allowable human exposure times and concentrations. Halons often protect computer and electronic systems that water or water-based agents might damage.

Dry Chemicals A number of dry chemicals are effective in extinguishing fires. They are most effective for flammable liquids and electrical fires. Certain types are also effective for ordinary combustibles. The ingredients are not toxic and are stable materials in fine powder form. They act primarily by smothering, cooling, and shielding fuel from the radiant heat of a flame. Nitrogen gas under pressure expels the agents.

Foams Foams are gas-filled bubbles formed from water-based and other materials. Foam applications primarily apply to flammable or combustible liquid spills and fires. The foam forms a layer that prevents vaporization of the liquid. They are sometimes used for Class A and Class B materials. Some foams are high expansion foams and can expand 100 to 1,000 times in volume. These foams can fill locations that are difficult to reach. Mixing nozzles or foam makers create the foam. Fixed foam systems can be actuated automatically. Aircraft rescue and industrial fires use portable equipment. The general design formula for high expansion foam systems for surface fires of flammable and combustible liquids with flash points above 100 °F is

$$R = (V/T + R_s) \times C_N \times C_L \qquad (16\text{-}8)$$

where

- R is the rate of foam discharge (cfm)
- V is the submergence volume (cubic feet) or volume of space to be protected
- T is submergence time (minutes) (normal range from design standards is 2–8 min)
- R_s is the rate of foam breakdown by sprinklers (cfm)
- C_N is the compensation for normal foam shrinkage (normally about 1.15)
- C_L is the compensation for leakage around door openings and so on. C_L varies from 1.0-1.2

R_s is normally determined from test data. Where data are unavailable, one may estimate R_s from the total discharge (gpm) from the maximum number of sprinklers expected to operate times 10.

Combustible Metal Agents For combustible metal fires, there are agents that will not react with the metals. Most agents are specific to particular metals. No single agent suits every kind of combustible metal. Most agents are proprietary. There are some nonproprietary agents, such as talc, sand, soda ash, and other materials. Each varies in effectiveness, but may be useful in certain applications.

16-10 FIRE DEPARTMENTS

In the United States, public fire departments, whether paid or voluntary, provide most fire protection services. Fire departments play important roles in the prevention of fires and by enforcing fire codes. They address the training and education of fire fighters and the community. They handle communication for fire alarms and other emergencies. They respond to fires and handle reporting and administration activities. Today fire departments are likely to respond more often to non-fire than fire emergencies. Hazardous materials and emergency medical responses are important parts of fire department operations.

There are many opportunities for engineers to contribute to fire department effectiveness. Engineers work with fire departments on the design of water systems, the site location for response units, modeling and monitoring response times, operational capabilities, the design of fire equipment, alarm designs in buildings, and communication equipment and systems.

In-Plant Organizations

Many industries and large facilities cannot depend solely on public fire departments. A lot of effort is needed within private organizations to ensure adequate fire prevention and protection. Many organizations have their own fire brigades. They handle immediate responses to fire calls in company properties, conduct training of employees and coordinate simulations and fire drills. They monitor facilities for fire hazards. They check exit routes to make sure they are clear. They handle routine inspection and testing of extinguishers, detectors, and other equipment.

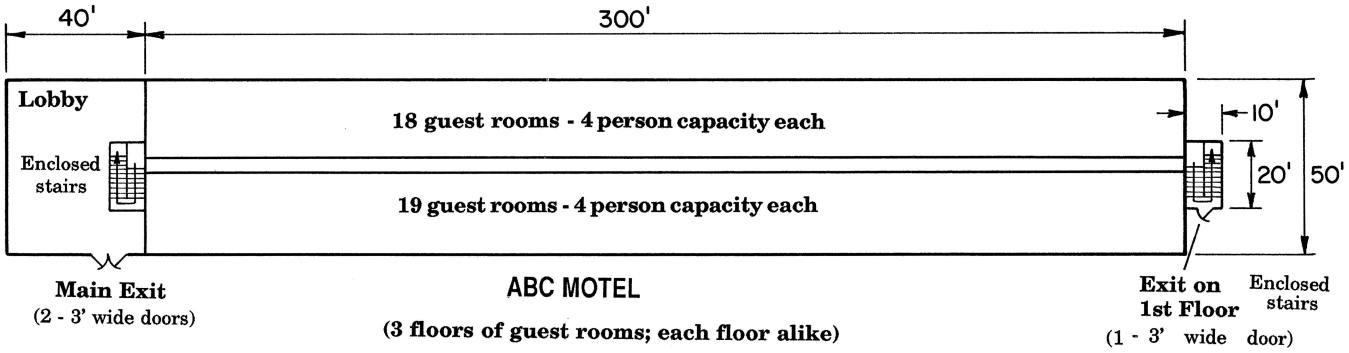
Mutual Aid Agreements

Mutual aid agreements are statements that one fire protection organization will assist another and vice versa when major responses occur. This reduces the personnel and equipment required by any one organization for severe situations. Not only do public fire departments establish such agreements, but many companies set them up with local departments and other nearby companies.

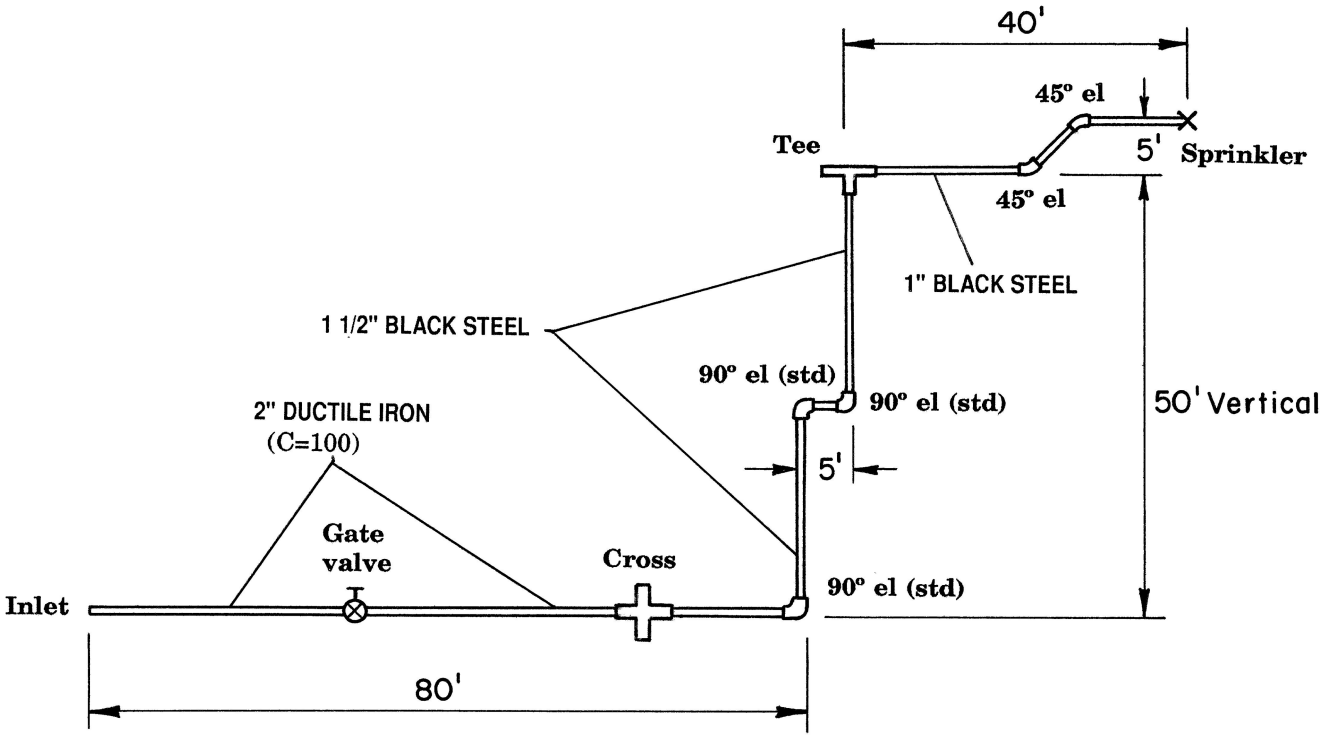
EXERCISES

1. Toluol (molecular weight = 92.13) will be used as a solvent in an operation. Compute the volume of vapor (cubic feet) produced by the evaporation of 1 gal. of liquid.

2. Using a dilution factor of 5 to account for nonuniform mixing, what ventilation rate (cubic feet per hour) will be required to keep toluol from reaching the LFL, if 3 gal. are evaporated each hour?
3. Eight gallons of turpentine are lost through evaporation because of a spill in an enclosed factory room. The room is 50 ft long, 120 ft wide and 20 ft high. Using a dilution factor of 3 for unequal mixing, determine if there is a danger of fire if all of the turpentine evaporates.
4. A drying oven has a volume of 50,000 ft^3. A production line runs through it. Parts suspended from the line are dipped in a degreasing tank and drained prior to entering the oven. The oven is vented with exhaust ventilation and air is replaced by clean air at a rate of 3000 ft^3/min. When the line and oven are running, 3 gal./hr of solvent are evaporated from the parts. At the beginning of the shift, there is no vapor present in the oven. A design distribution constant $K = 4$ is used to allow for incomplete mixing of vapor in the oven. The solvent has a vapor equivalent of 23 ft^3/gal. The LFL and UFL for the solvent are 1.4 and 8.3, respectively.
   (a) Assume that at startup there is no delay in the solvent-soaked parts filling the oven. How long will it take following startup before the concentration of solvent in the oven reaches 100 ppm?
   (b) What will the concentration of solvent vapor be in the oven after 1.5 hr?
   (c) If the line starts but the exhaust ventilation system is not turned on, how many gallons of solvent will evaporate before a flammable mixture is reached? Assume uniform distribution of vapors.
   (d) If the line stops but the exhaust ventilation system keeps running, how long will it take to reduce a 200 ppm concentration to 50 ppm? Assume the evaporation stops when the line stops.
5. The area formed by combustibles in a manufacturing facility is 35×40 ft. There are curtain boards extending 12 ft from the ceiling that end 15 ft above the floor. What area of roof venting is needed between curtain boards spaced 175 ft apart in a square pattern? Assume the combustible area falls within one section bounded by curtain boards.
6. An office room measures 40×60 ft. It contains 2000 lb of paper stored openly, 1500 lb of paper stored in file cabinets and 1200 lb of paper manuals stored in open book shelves. Assume the paper has a heat content of 8000 BTU/lb. What is the total fire load in the room?
7. A three-story motel is on the drawing board. The accompanying illustration shows guest room layouts for each floor. Consider only the residential section. Assume the lobby is unoccupied. Determine the following from the current *Life Safety Code*® (NFPA 101):
   (a) What is the occupant load for determining the amount of fire exits?
   (b) How many exit units are required for the motel?
   (c) Is the travel distance to exits from any room exceeded?
   (d) Assume the travel distance for rooms in the center of a floor is too long. What redesign alternatives would make the travel distance satisfactory.
   (e) What fire resistance rating must the walls enclosing the stairways have?
   (f) What fire resistance rating must the walls between guest rooms have?
   (g) The designers are considering carpet for the corridors. The manufacturer certifies that the carpet selected has a flame spread rating of 81. Can it be installed in the corridors?
   (h) Could the same carpet be used in the guest rooms?
   (i) Do the exit stairs satisfy the code?
8. A sprinkler head has a discharge rate of 22.5 gal./min and a coefficient $K = 5.65$. What pressure is required at the sprinkler head?
9. For the wet-pipe sprinkler line shown in the accompanying diagram, what pressure is required at the inlet if



Exercise 16-7. Diagram for Exercise 16-7.



Exercise 16-9. Diagram for Exercise 16-9.

the discharge rate must be 22.5 gal./min and the sprinkler head has a coefficient K = 5.65? Assume that fittings connecting two different-sized pipes have the size of the smaller pipe. Assume that pipe diameters d equal the nominal diameters.

10. For the facility layout shown in the accompanying sketch, complete the sprinkler system layout using NFPA 13. The cross-mains are already located, placed on one side of the building, and the branch lines should extend across the room from the cross-main.

- **(a)** Locate branch lines and sprinkler heads on branch lines. Dimension locations along branches and between branches and walls.
- **(b)** How many sprinklers are required for each of the three zones to meet all design criteria?
- **(c)** What size copper tubing is required for the branch lines in the extra hazard zone?

11. Identify the NFPA occupancy classification for

- **(a)** a retail store
- **(b)** an elementary school

REVIEW QUESTIONS

1. Describe total fire losses for the United States each year in cost and deaths.

2. What causes most deaths in fires?

3. For what age groups is death from fire most prevalent?

4. Describe the relationship between alcohol use and fires.

5. In what kind of building do most fatal fires occur?

6. What is the leading cause of civilian fires?

7. What are the two leading causes of industrial fires?

8. To what extent are arson and incendiary fires a significant element in the fire losses?

9. What organization is the main source for fire codes and standards in the United States?

10. Define:

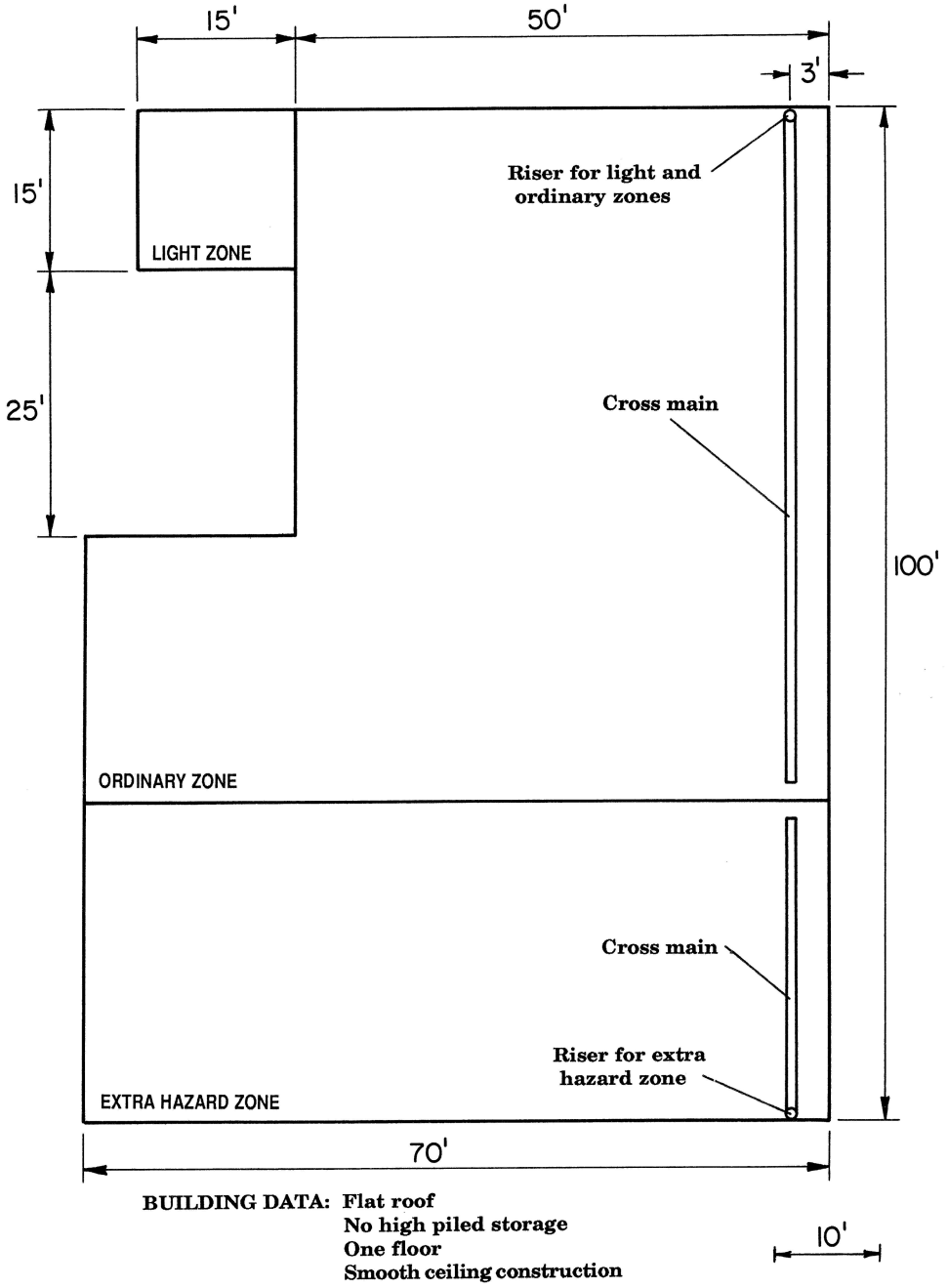
- **(a)** combustion
- **(b)** ignition
- **(c)** spontaneous combustion
- **(d)** the fire triangle
- **(e)** the fire pyramid

11. Name four methods for controlling combustion and for extinguishing fires.

12. Name three products of combustion and the danger of each.

13. Describe the movement of hot gases produced by fire in

- **(a)** a horizontal building
- **(b)** a vertical building.



Exercise 16-10. Diagram for Exercise 16-10.

14. Define or characterize each of the following for a flammable or combustible liquid:

(a) flash point

(b) fire point

(c) vapor pressure

(d) vapor volume

(e) lower flammable limit

(f) upper flammable limit

(g) flammable range

15. Define:

(a) flammable gas

(b) char

16. Describe the NFPA symbol and method for identifying hazardous materials and their properties.

17. What are the goals for fire safety in buildings?
18. Identify at least three requirements for site planning that are important for fire safety.
19. What are four characteristics of buildings that are important in designing for fire safety?
20. Explain the following:
    (a) compartmentation
    (b) firestopping
    (c) fire load
    (d) fire resistance rating
    (e) flame spread rating
21. How can the buildup and lateral movement of heat from a fire in a single-story factory be minimized?
22. What are the fire hazards of welding and cutting and how can they be controlled?
23. Identify at least three ways to minimize fire hazards of flammable liquids stored indoors.
24. What is life safety?
25. What aspects of building design do life safety features address?
26. Define:
    (a) exit unit
    (b) exit
    (c) exit route
    (d) exit access
    (e) exit discharge
    (f) exit capacity
    (g) occupant load
27. Name at least four kinds of detectors for fire protection and describe the function of each.
28. Describe the materials included in each for the four classes of fires.
29. Identify and describe five kinds of sprinkler systems.
30. What are the two approaches for designing sprinkler systems?
31. How does each of the following accomplish fire extinguishment?
    (a) water
    (b) carbon dioxide
    (c) halons
    (d) dry chemicals
    (e) foams
    (f) agents for combustible metals
32. What is a mutual aid agreement? Who are the usual parties in such an agreement?

NOTES

[1]www.nfpa.org/research/reports-and-statistics/fires-in-the-us

[2]www.usfa.fema.gov/data/statistics/; www.usfa.fema.gov/downloads/pdf/statistics/v12i8.pdf

[3]www.nfpa.org/research/reports-and-statistics/printable-fact-sheets

[4]www.osha.gov/dte/library/flammable_liquids/flammable_liquids.html

[5]www.nfpa.org/Assets/files/AboutTheCodes/30/30_FAQs.pdf

[6]NFPA 704-1990, *Identification of the Fire Hazards of Materials*, National Fire Protection Association, Boston, MA.

[7]NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*; NFPA 491, *Manual of Hazardous Chemical Reactions*; and NFPA 325, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*.

[8]NFPA 220, *Standard on Types of Building Construction*; NFPA 5000, *Building Construction and Safety Code®*.

[9]www.nfpa.org/codes-and-standards/document-information-pages

[10]NFPA 101, *Life Safety Code®*.

[11]NFPA 101, *Life Safety Code® Handbook*.

[12]www.usfa.fema.gov/pdf/efop/efo39033.pdf

[13]NFPA 10, *Standard for Portable Fire Extinguishers*.

[14]NFPA 13, Standard for the Installation of Sprinkler Systems.

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CHAPTER 17

EXPLOSIONS AND EXPLOSIVES

17-1 EXPLOSIONS

General Characteristics

The term explosion does not have a precise definition. In general, it refers to a group of phenomena in which there is a sudden expansion or bursting effect. One definition focuses on a rapid increase of pressure. Another includes an excessively high pressure in a confined space followed by its sudden release due to rupture of the container. In some explosions there are visible flames and a flash of light. Other explosions involve material flying in many directions. Explosions produce a noticeable sound described as a "crack" or "boom." The sound depends on the location of an observer relative to the source and on atmospheric and other conditions.

Some controlled explosions are very useful. For example, explosions occur inside cylinders of internal combustion engines. Blasting materials are common to certain mining, tunneling, and quarrying activities.

Accidental or uncontrolled explosions can have disastrous effects. Spectacular explosions of various types gain widespread attention. One of the most notable was the space shuttle Challenger explosion on live television in 1986.[1] Others are grain elevator explosions[2] and explosions of railroad tank cars and storage vessels containing liquid petroleum gas (LPG)[3] and other materials. Although the visible effects appear similar, the phenomena are not exactly alike.

Explosive materials are common in military operations with the intent of destruction. When explosive materials get into the hands of terrorists, security of plants, operations, and communities becomes a concern. Chapter 29 discusses some aspects of physical security.

Kinds of Explosions

There are various schemes for classifying explosions. For the relatively common explosions produced by an exothermic chemical reactions (sometimes called combustion explosions), there are two main types: deflagration and detonation.

A *deflagration* is an exothermic reaction that expands rapidly from the burning gases to the unreacted material by conduction, convection, and radiation. The combustion zone progresses through the material at a rate that is less than the velocity of sound. Not all deflagrations produce sufficiently rapid increases in pressure to create an explosion.

A *detonation* is an exothermic reaction characterized by the presence of a shock wave in the material that establishes and maintains the reaction. A detonation usually results in sufficiently rapid increases in pressure to produce an explosion. The reaction zone expands at a rate greater than the speed of sound in the unreacted material.

A more detailed classification scheme considers a variety of phenomena. Classifications differ somewhat among sources.

Condensed Phase Detonations Condensed phase materials are high explosives and propellants. Such materials have detonated during manufacturing, transportation, storage, and use. Certain compounds of this type decompose almost instantly in a violent reaction. Most produce hot gases.

Acetylene, hydrogen, and certain metallic azides can produce rapid decomposition. Ammonium nitrate is also a material that can produce condensed phase detonations.

Combustion Explosion of a Gaseous or Liquid Fuel in an Enclosure These explosions have two groups based on the length-to-diameter ratio (L/D) of containers. Many buildings, ship holds, and boilers are containers. For containers with an $L/D \approx 1$, there is a relatively slow rise in pressure. The overpressure will cause the container to rupture.

Containers with large L/D ratios are pipes and certain buildings or tanker ships. The dynamics of the flame front and the turbulence of the gases in front of it are important in explosions occurring in this container class. As a flame propagates, it creates turbulence in front of it. The turbulence improves mixing, which expands the flame area and speed of travel. Pressures can increase very rapidly by as much as 20 times. Some pressures reach 15–20 atm. The greatest damage often occurs at points distant from the source of ignition. If a rapidly accelerating flame front and pressure wave become reflected from a surface, the pressure may double again. For example, this type of explosion can occur in compressed-air

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CASE 17-1

April 16, 1947, Texas City, TX. The greatest explosion disaster in U.S. history occurred on April 16, 1947 in Texas City, TX. Texas City had a population of about 16,000. A cargo ship, the *S.S. Grandcamp*, was docked and taking on a load of ammonium nitrate fertilizer in bags. Workers completed loading about 2,300 tons before rain interrupted the work overnight. In the morning crew members smelled smoke in one of the holds and found a few bags of fertilizer on fire. Extinguishers did not put the fire out.

The local fire department arrived and started spraying water. The fire continued. (Ammonium nitrate deteriorates at 350 °F.) A short time later the ship exploded. The blast flattened 20 waterfront blocks and 12 blocks inward. Debris and shrapnel flew high into the air striking two airplanes and causing them to crash. Some pieces of the ship blew 5 miles away. Fires along the docks continued burning.

Another cargo ship located nearby was the *S.S. Highflyer*. It contained ammonium nitrate, also. The first explosion led to fire on the second ship and a second explosion about 16 hours later.

Overall, authorities identified 405 as dead, 63 as unidentified dead and about 150 more as missing. The disaster destroyed about 1,500 homes and buildings, about one-third of the city's housing. About 2,000 were homeless. Property damage was more than $600 million in 1947 money.[a,b,c]

The event led to changes in chemical manufacturing, storage, handling and shipping. There were also many legal challenges. Some were precedence setting.

[a] www.youtube.com/watch?v=qH7t4X9hgBc
[b] archive.wired.com/science/discoveries/news/2009/04/dayintech_0416#
[c] DECKARD, IVY STEWART, *In the Twinkling of an Eye*, Vantage Press, New York, 1962.

lines, where fuel from compressor lubricants and enriched oxygen are usually present.

Combustion Explosions of Dusts in an Enclosure

Dust explosions most often occur in containers with dust distributed in the atmosphere. They can also occur when some activity suddenly creates a cloud of airborne dust in the presence of an ignition source. Similar to gas and vapor explosions, dust explosions show effects related to the L/D ratio of the container.

Some refer to the elements involved in this type of explosion as the dust explosion pentagon. See Figure 17-1. For a dust explosion there must be the three elements of the fire triangle (see Figure 16-1a), fuel, oxygen, and heat or flame. In addition, there must be a fourth element, dispersion. Dust particles must be dispersed in the air. Also, there must be the fifth element, confinement. While airborne, many kinds of dust will burn. But there will not be significant heat and pressure buildup from the combustion unless the airborne dust is confined.

Boiling Liquid-Expanding Vapor Explosions (BLEVE)

When a container holding a liquid at a temperature well above its boiling point ruptures, the liquid will evaporate or boil rapidly into a vapor state. The sudden expansion, a physical phenomenon, can throw parts of the container

CASE 17-2

A plant producing glass bottles required large amounts of compressed air to inflate molten glass into shapes within molds. Large air compressors provided the necessary air at desired pressures.

A fire started inside a compressed air line. The valves in the piston type compressor allowed a small amount of lubricant to enter the compressed air. The lubricant accumulated in a collection point within the large pipe. Small amounts of carbon built up on the edges of the exhaust valves. At times, a heated and glowing fragment broke loose and moved down the compressed air stream. A heated fragment ignited the accumulated lubricant. Because the air was under pressure (enriched atmosphere), the lubricant burned readily, once ignited. The line filled with smoke and incompletely burned lubricant.

When workers detected burning lubricant in the line, the normal procedure was to turn a large wheel that closed a valve in the line. A worker proceeded to turn the valve by hand. About that time, the content of the line exploded. A pressure wave moved down the line to the closing valve and reflected, raising the pressure at the valve even higher. The valve blew apart and tore the worker's hands from his arms.

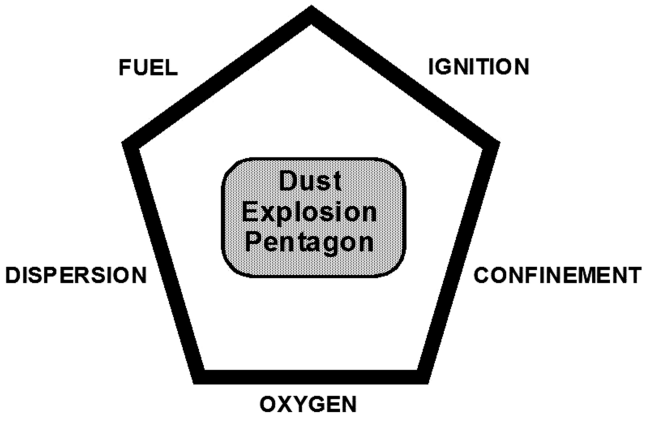


Figure 17-1. Dust explosion pentagon.

considerable distances. This phenomenon includes sudden releases of pressurized steam. Fire may accompany a BLEVE if the material is combustible. Then thermal effects add to the physical effects. The heat of the fire can increase the rate of pressure rise and the pressure achieved. BLEVEs involving LPG produce spectacular fireballs, noted in Case 17-3.

Explosions of Pressure Vessels Containing Nonreactive Materials This type of explosion has similarities to a BLEVE. It is typical for a pressure vessel with a weak structure that will fail at quite low pressures (less than 2 lb/in.^{2} (gauge)). Materials are not thrown as violently as in a BLEVE. The pressure vessel itself may have severe damage from the rapid expansion of steam or from a combustion explosion within the vessel.

Unconfined Vapor Cloud Explosions Unconfined vapor clouds are open-air concentrations of fuels in vapor form. The cloud can dissipate to a harmless condition (from a flammability viewpoint) in which the concentration is too low to burn. In some cases, a source can ignite a cloud as contents exit a container. If ignited at a somewhat controlled rate, little overpressure results. However, if a cloud becomes ignited and the flame accelerates rapidly enough, a dangerous blast wave can result.

Deflagrations of Mists If fuels dispersed in air are in the form of a fog or mist and concentrations fall within flammable limits, ignition can produce violent deflagrations.

Chemical Reactor Runaway Chemical reactions may create too much pressure for the container holding the material. Inadequate cooling, insufficient stirring, too much catalyst and other factors may cause the reaction to go out of control. In a sealed container, pressure increases may result from the reaction itself and from temperature increases following the Boyle-Charles law (see Chapter 19).

Nuclear Reactor Runaway or Nuclear Detonations A nuclear detonation occurs when fission or fusion rearranges the structure of nuclei. Energy in an air detonation of a nuclear device becomes converted into a blast wave, thermal radiation, and nuclear radiation. For a nuclear reactor runaway, the rate of decomposition is much less than that of a weapon. The likelihood of a runaway reactor is very low because control systems included in the reactor design prevent such occurrences.

The Chernobyl reactor explosion[4] on April 26, 1986, was a runaway event for one type of reactor design. It involved a steam explosion. Heat from the reaction caused the explosion in the plant. It was not a nuclear explosion like that in a bomb. The major incident at Three Mile Island, PA, involved a runaway reaction, but no explosion.[5]

17-2 EXPLOSION HAZARDS

There are three main causes of damage and injury from explosions. The most common cause of damage or injury is a blast wave or pressure wave that radiates from the explosion. Another cause of damage or injury is thermal radiation from combustion. A third source of damage and injury stems from projectiles (flying metal, glass, wood, etc.) created by an

CASE 17-3

September 3, 1983, Murdock, IL. A railroad derailment included 11 tank cars. Some caught fire and burned for several hours. Eventually, a tank car containing about 30,000 gal of liquid propane exploded, creating a spectacular fireball. A major portion of the tank car flew about 3/4 of a mile from its original position.

That led to an explosion of another car containing 50,000 gal of iso-butane. The fireball was so intense it turned a video image white for several seconds.[a,b]

[a] www.youtube.com/watch?v=Xf3WKTwHpIU
[b] http://gizmodo.com/5976153/25-of-the-deadliest-explosions-man-ever-made

explosion. A blast wave impacting on a secondary object may produce additional projectiles.

Blast Wave Effects

A free-field blast wave emanates from an explosion until it reaches an object and interacts with it. Sources of explosions that have very high energy and power densities produce ideal blast waves that have predictable properties. A blast wave decays with distance from the source. For high explosive materials, the distance for a blast wave is related to the cube root of the charge weight. In some cases, one can estimate the forces involved in an explosion from the fragment distribution pattern.

The interaction of a blast wave with an object is complex. The reflections can produce local pressures that are much higher than that of the blast wave itself. The object struck may bend or break. The damage produced is related to pressure, impulse (duration), and drag force. Table 17-1 lists typical damage due to various overpressures.

Thermal Effects

A combustion explosion produces a fireball. Radiation damage from a fireball is a function of the size of the fireball and its duration. Most fireballs reach temperatures near 2400 °F. The radiant energy decreases with the square of the distance from the fireball. Accurate predictions of thermal damage are difficult because the distance, surface material receiving radiation, and other factors affect the damage level.

Scatter of Fragments

Fragment damage is also difficult to predict. Scatter depends on the size of the explosion and failure modes for materials involved. For example, glass will fragment quite easily and scatter, whereas tougher, more ductile materials may not scatter as much. Explosions may throw tougher, ductile materials farther because they do not fragment.

TABLE 17-1 Blast Wave Effects Due to Overpressure

Approximate Overpressure ($lb/in.^2$)	Effect
0.5–1.0	Shatter glass
1.0	Knock a person down
2–3	Shatter 8–12 in. block or concrete wall
5	Snap utility pole
7	Overturn loaded railroad car
11	Threshold for lung damage
15	50% of eardrums are ruptured

The orientation of a container (building, tank. etc.) can affect the likely points for failure. An internal pressure wave will be greater along a container's long axis or orientation. The greatest damage will occur at the ends of the axis. Fragments are likely to move in the direction of the internal pressure wave. The presence of container venting and use of pressure relief devices can affect the degree and amount of fragmentation and the scatter pattern.

In some cases, the release of gases in an explosion can cause a container, such as a cylinder or tank, to act like a missile, particularly when there is a failure at one end of the container. An example is an acetylene tank used in gas welding. If the neck for the control valve breaks, the cylinder can become a missile as pressurized gas escapes.

17-3 DUST EXPLOSIONS

Description

Dust explosions result when there is dispersion of fine particles in air and a heat or flame source ignites the particles. A flame front spreads rapidly through the contaminated air and pressure and temperature increase. Virtually all organic dusts, some inorganic dusts, and certain metallic dusts are combustible in air and can explode. In some situations, inert dusts, like limestone, are an extinguishing agent.

Dust must be airborne to burn readily. Some operations cause dusts to become airborne. Dust that has settled on equipment, in ducts or on parts of structures can become airborne if disturbed. Dust explosions frequently occur as a sequence of explosions. A first explosion may cause accumulated dust to become airborne and result in a second explosion. A fire may start in a pile of dust on a hot piece of equipment. and a water stream from a fire hose or the agent expelled from an extinguisher may throw the dust into the air, producing an explosion.

The severity of a dust explosion is a function of the material. Compared to combustible dusts, oxidizing dusts can accelerate the combustion process. If oxidizing agents mix with combustible dust, the resulting explosion will be even more severe. Some materials will burn more readily than others, producing higher rates of pressure and temperature buildup.

Other properties of dusts that affect the likelihood of ignition and the severity of combustion include particle size, concentration, oxygen presence, presence of impurities, moisture content, and air turbulence. Small particles ignite easier than large particles. Fine dusts often have high rates of pressure rise during combustion. Similar to flammable gases and vapors, certain concentrations of dusts in air are combustible. Particle size affects the concentration required for combustion. If a concentration is too low, combustion is not likely. The presence of inert material in a dust can reduce its

TABLE 17-2 Relative Explosion Hazard of Dusts

Type of Explosion	Ignition Sensitivity	Explosion Severity	Explosibility Index
Weak	< 0.2	< 0.5	< 0.1
Moderate	0.2–1.0	0.5–1.0	0.1–1.0
Strong	1.0–5.0	1.0–2.0	1.0–10
Severe	> 5.0	>2.0	>10

ability to burn. As the moisture content of dust increases, the ignition temperature of the dust increases. The rate of combustion increases with the partial pressure of oxygen. Therefore, the presence of inert gas can help reduce the likelihood of dust explosions. Combustible dust mixed with air will have faster combustion and more violent explosions when mixed turbulently.

Indices of Dust Explosion Hazard

Data tables in references, such as such as the *National Fire Code* and the *Fire Protection Handbook* provide explosion properties of dusts. The Bureau of Mines developed some indices to represent the relative hazard of various dusts. There are three indices: ignition sensitivity, explosion severity, and explosibility index. The latter is the product of the first two. Ignition sensitivity and explosion severity come from laboratory tests. The tests compare the properties of a dust to a reference dust, standard Pittsburgh coal dust. The ignition sensitivity is a function of ignition temperature, minimum energy of ignition, and minimum concentration. Explosion severity is a function of maximum explosion pressure and maximum rate of pressure rise. The rating scale in Table 17-2 classifies the relative hazard of a dust. Table 17-3 lists the explosion properties of a few dusts.

17-4 CONTROLS FOR EXPLOSIONS

The appropriate controls for preventing an explosion or reducing the damage an explosion causes vary with each application. The following text will summarize controls. Planning, training, procedures, and enforcement are also important. There are specialized software products for analyzing pressure waves from explosions and simulating impacts on buildings and building element.[6] The Society

TABLE 17-3 Explosion Properties of Selected Dusts

Dust Type	Explosibility Index	Ignition Sensitivity	Cloud Explosion Severity	Ignition Temperature (°C)	Min. Cloud Ignition Energy (J)	Min. Explosion Concentration (oz/ft^2)
Aluminum fines	> 10	1.4	7.7	760	0.05	0.045
Benzoic acid	> 10	5.4	2.1	620	0.02	0.03
Cellulose	2.8	1.0	2.8	480	0.08	0.055
Cellulose acetate	> 10	8.0	1.6	420	0.015	0.04
Charcoal (hardwood mix.)	1.3	1.4	0.9	530	0.02	0.14
Cinnamon	5.8	2.5	2.3	440	0.03	0.06
Coal (Pittsburgh)	1.0	1.0	1.0	610	0.06	0.055
Corn	6.9	2.3	3.0	400	0.04	0.055
Grain Dust	9.2	2.8	3.3	430	0.03	0.055
Magnesium (milled)	> 10	3.0	7.4	560	0.04	0.03
Nylon polymer	> 10	6.7	1.8	500	0.02	0.03
Peanut hull	4.0	2.0	2.0	460	0.05	0.045
Polystyrene molding compound	> 10	6.0	2.0	560	0.04	0.015
Polyurethane foam, not fire retardant	> 10	6.6	1.5	510	0.02	0.03
Rubber, crude, hard	7.4	4.6	1.6	350	0.05	0.025
Rubber, synthetic, hard, contains 33% sulfur	> 10	7.0	1.5	320	0.03	0.03
Salicylanilide	5.8	4.1	1.4	610	0.02	0.04
Sugar, powdered	9.6	4.0	2.4	400	0.03	0.05
Sulfur	> 10	20.2	1.2	190	0.015	0.035
Titanium	> 10	5.4	2.0	510	0.025	0.045
Vitamin C (ascorbic acid)	2.3	1.0	2.2	460	0.06	0.07
Wheat flour	4.1	1.5	2.7	440	0.06	0.05
Wood flour (white pine)	9.9	3.1	3.2	470	0.04	0.035

CASE 17-4

April 17, 2013, West, TX. A local fertilizer company stored about 50 tons of ammonium nitrate in its facility just outside of the city. The facility caught fire. Several members of the local volunteer fire department responded to control and extinguish the fire in the burning structure. Without notice the ammonium nitrate exploded, killing ten firefighters and three others living near the plant.

The blast damaged a nearby apartment building, nursing home and high school. About 100 people received injuries.

Several state and federal government agencies investigated the incident and issued reports. There were many recommendations. One focus was on closer regulation of ammonium nitrate and associated storage facilities.[a,b,c,d,e]

[a] http://res.dallasnews.com/West/#the_toll
[b] http://abcnews.go.com/blogs/headlines/2014/04/remarkable-new-video-of-west-texas-explosion/
[c] cdc.gov/niosh/fire/pdfs/face201311.pdf
[d] csb.gov/assets/1/19/west_preliminary_findings.pdf
[e] tdi.texas.gov/reports/fire/documents/fmloddwest.pdf

for Modeling and Simulation International[7] members include people specializing in this analysis.

Limit Quantities of Materials

If there are small amounts of materials that can explode at any location, the likelihood of an explosion will be low and the amount of damage will be small if an explosion occurs. The likelihood of an explosion will also be reduced in many cases, because there is less opportunity for ignition.

OSHA and NFPA have standards about the amount of flammables and combustibles stored in work areas where there is high risk to workers. It is best to store large quantities in remote areas where there is reduced risk to people and property. For many years standard references tables prescribed limits on the amounts of explosive materials in one place or structure. There are standards for the design of facilities storing explosives.

In locations where dust can accumulate, regular cleaning will reduce the likelihood and severity of explosions. Building designs can reduce places for dust to accumulate.

Compressed air lines with traps and accumulators will minimize buildup of flammable oils in lines. Compressed air lines require routine cleaning or purging to minimize fire and explosions within the pipes.[8]

Prevent Combustible Concentrations

Designs should prevent and manage combustible and explosive mixtures in air. Particularly important are processes and operations where flammable mixtures of gases, vapors, and dusts with air can occur, This principle includes reducing oxidizers that add to the explosive energy of a combustible material. Fuel and oxidizers require separated storage. That is because of the increased risk when fuels and oxidizers are located adjacent to or near each other.

Monitoring equipment can help detect explosive concentrations of gases and provide warnings or activate ventilation or other equipment to reduce the hazards.

Another approach is limiting the amount of explosive material in one place. Case 17-1 and Case 17-4 both involve concentrations of ammonium nitrate that become explosive when heated.

Eliminate Sources of Ignition

If there is the potential for an explosive atmosphere, sources of heat, flame, and sparks must be kept away or carefully controlled. Some companies have operational rules preventing workers from carrying any kind of smoking material, matches, or lighters on company premises. Also, there is a need for a hot work permit system. Moving belts and other sources of static electricity require electrical grounding. Electrical equipment (switches, fixtures, motors, etc.) must meet hazardous environment standards, such as being sealed to prevent a dusty atmosphere from reaching sources of heat or sparks. Such equipment must meet electrical code requirements for explosive atmospheres. By itself, this means of prevention is not dependable. In many operations, such as those in grain elevators and factories, it is very difficult to eliminate every source of ignition.

Reduce Oxygen

A protection for some containers or environments that could produce explosive mixtures involves keeping oxygen concentrations low. An inert gas, such as nitrogen, may replace air. However, people cannot enter such environments without an independent source of breathing air. It is important to avoid elevated oxygen concentration above atmospheric levels and compressed oxygen mixtures which elevate the partial pressure of oxygen. Elevated partial pressures of

oxygen increase the potential for combustion and accelerate combustion.

Provide Overpressure Relief

In containers, including tanks and buildings, where there is a potential for explosive mixtures or releases, there should be pressure relief devices. Venting is a passive means for minimizing damage from an explosion. In some cases, such as pressurized vessels and boilers, venting can prevent an explosion. Chapter 19 discusses pressure relief valves, fusible plugs, and other devices. There are ways to design explosion venting for buildings.[9] Explosion relief vents built into walls and roofs help prevent pressure buildup if an explosion occurs. There are also designs for sashes, window panels, and doors to relieve explosive pressures. The quantity and design for explosion relief depend on the rate of pressure rise expected, the L/D ratio of the container, the type of explosive material, and other factors.

Install Extinguishing and Suppression Systems

If a fire occurs that could lead to an explosion, extinguishing equipment may put out the fire and prevent an explosion. However, some kinds of extinguishing equipment may add to the potential for explosion in certain situations. For example, equipment that distributes dust into the air in a fire can lead to an explosion. Water streams or extinguisher action may stir up dust. When flame is present, a dust explosion could result.

There are some special suppression systems for explosions[10] that provide an active means for minimizing damage. They must act very quickly to detect an explosion and minimize any effects.

Apply Distance and Barriers

One way to reduce the severity of an explosion is to separate quantities of materials by distance and barriers. A blast wave deteriorates with distance and a barrier that can withstand a blast wave will reduce the energy of the wave.

Haddon's Energy Theory (Chapter 3) for reducing risks is just one construct involving potential use of distance and barriers.

Provide Remote Controls

If there are conditions where combustion can lead to explosion, there should be remote controls for valves and equipment. During normal operation, manual controls on equipment may not be hazardous, but if there is a danger of explosion, remote controls will avoid the need for operators to enter dangerous areas.

17-5 EXPLOSIVES

An explosive is a chemical compound or mixture of substances used or intended for creating a rapid, self-propagating reaction and explosion. Explosives release energy in the form of heat and pressure. Explosive materials include explosives, blasting agents, slurries, and detonators. There are various ways to initiate a reaction within an explosive. The methods depend on the type of substance. Ignition methods include fire, friction, concussion, percussion, or detonation.

The U.S. Department of Transportation defines an explosive as:

> An explosive means any substance or article, including a device, which is designed to function by explosion (i.e., an extremely rapid release of gas and heat) or which, by chemical reaction within itself, is able to function in a similar

CASE 17-5

March 23, 2005, Texas City, TX. Explosions and fires occurred at the BP refinery. The incident killed 15 people and injured 180 others. The financial loss was more than $1.5 billion. (See also Case 9-3.)

The incident occurred during startup of an isomerization unit, which converts normal pentane and hexane to higher octane hydrocarbons used in gasoline blending. This facility is the third-largest refinery in the United States.

The U.S. Chemical Safety and Hazard Investigation Board studied the incident.[a] Based on its findings, the organization made several recommendations that included:

1. Promoting a safety culture involving effective process safety leadership, knowledge and expertise, management accountability and other factors.
2. Trailer siting that places temporary work structures safely away from hazardous areas.
3. Improvements in blowdown drum and stack applications.

[a]www.csb.gov/assets/1/19/csbfinalreportbp.pdf

TABLE 17-4 GHS and DOT Divisions for Class 1 Explosives[a]

Division	Definition
1.1	Explosives that have a mass explosion hazard. A mass explosion is one which affects almost the entire load instantaneously.
1.2	Explosives that have a projection hazard but not a mass explosion hazard.
1.3	Explosives that have a fire hazard and either a minor blast hazard or a minor projection hazard or both but not a mass explosion hazard.
1.4	Explosives that present a minor explosion hazard. The explosive effects are largely confined to the package and no projection of fragments of appreciable size or range is to be expected. An external fire must not cause virtually instantaneous explosion of almost the entire contents of the package.
1.5	Very insensitive explosives.
1.6	Extremely insensitive articles which do not have a mass explosion hazards

[a]49 CFR 173.50

> manner even if not designed to function by explosion, unless the substance or article is otherwise classed under the provisions of this subchapter. The term includes a pyrotechnic substance or article.[11]

The U.S. Department of Transportation organizes explosives to follow the Globally Harmonized System (GHS) of classifying chemicals (see Chapter 24). Explosives are Class 1 materials in the GHS definitions and further divided into Divisions. Table 17-4 lists the DOT and GHS Divisions for explosives.

DOT and GHS explosive classification system recognizes that some kinds of explosives are not compatible with others. During transport or storage, placing incompatible explosives together increases their hazard level. In order to address this issue, DOT identifies 35 compatibility groups and charts the combination of the hazard divisions and compatibility groups.[12]

Many organizations in the U.S. adopted explosive classifications held by the U.S. Department of Transportation for many years prior to using the GHS classifications. The old classification system used three classes: Class A, Class B, and Class C. DOT offers a conversion between the old system and the new system.[13] The three classes, still in use by some, are:

1. *Class A.* These explosives possess a detonating hazard. They are divided into many types, including black powder, low explosives, high explosives. dynamite, nitroglycerine, picric acid, lead azide, blasting caps, detonating primers, shape charges, and ammunition.
2. *Class B.* These are explosives that, in general, function by rapid combustion rather than detonation. Included are fireworks, flash powders, pyrotechnic signal devices, some liquid or solid propellant explosives, some smokeless powders, and certain ammunition.
3. *Class C.* These are certain types of fireworks or manufactured articles that contain Class A or Class B explosives or both as components in restricted quantities and certain types of fireworks.

Many organizations establish standards and regulations for explosives. Besides DOT, the Bureau of Alcohol. Tobacco, and Firearms, OSHA, MSHA, and state and local governments have regulations on explosives. The Institute of Makers of Explosives, NFPA and other organizations set some standards used by various government agencies. A longstanding reference on explosives and their use is the *Blasters' Handbook.*

Hazards

Explosives are dangerous materials. They create damage from heat and pressure waves. The primary hazard is release of their energy in the wrong place and at the wrong time. The quantity and type of material activated determine the degree of damage for a particular place and time. Release in the presence of people can cause serious injury or death. The injury may be from the heat or pressure wave or from materials thrown by the pressure wave. Properly used, explosives can serve useful functions. They are essential for mining, excavating, demolition, and similar activities.

Controls

Minimizing explosive hazards includes applying controls during manufacture, distribution and use. Controls include training and licensing of handlers, users, and distributors. Manifesting explosive materials from factory to final use minimizes reaching unqualified users or improper use. Many states require licensing of those involved with explosives after meeting required training and examination.

Another control is proper storage. Blasting caps and detonating devices must have storage separate from explosives. Standards limit the quantities in magazines or in daily use. They specify the separation distance between magazines and from transportation routes and buildings. Most quantity-distance tables come from the American Table of Distances for Storage of Explosives (see Table 17-5) developed by the Institute of Makers of Explosives.

TABLE 17-5 American Table of Distances for Storage of Explosives (abbreviated)[a,b]

Quantity of Explosives (lb)	Minimum Distance between Magazines	Distance from Inhabited Building	Distance from Public Highway	Distance from Passenger Railways and High Traffic Highways[c]
Over-Less Than	(ft)	B (ft)	(ft)	(ft)
0–5	12	140	60	102
10–20	20	220	90	162
40–50	28	300	120	220
100–125	36	400	160	300
200–250	46	510	210	378
500–600	62	680	270	506
1,000–1,200	78	850	330	636
2,000–2,500	98	1090	380	816
5,000–6,000	130	1460	470	1092
10,000–12,000	164	1750	540	1374
20,000–25,000	210	2000	630	1752
50,000–55,000	280	2000	880	2000
95,000–100,000	370	2000	1090	2000

[a]June 1991 Edition
[b]Distances shown are for unbarricaded magazines. They may be reduced by 1/2 for quantities under 10,000 lb, if properly barricaded. For large quantities, allowable reductions in distance vary.
[c]More than 3000 vehicles per day.

Magazines, the storage facilities for explosives, must meet design specifications. Design criteria include fire resistance, impedance to firearms, physical security, location, and other factors. Magazines must meet standards that vary with the quantity of material stored. Distances between magazines or between a magazine and a building, highway or railway are less if there is a proper natural or artificial barricades. Barricades often are mounds of earth or walls of timber that will prevent material from an exploding magazine from affecting the adjacent structures, highway, or railway.

Implosions

An implosion is a sudden, inward collapse of a building or closed container when the external pressure is greater than that inside the container sufficient to produce structural failure in some structural element. An implosion can also be the inward collapse of a building or structure during controlled demolition using explosive charges intended to create failure in structural elements (columns, beams, etc.).

For planned implosions, humans must be a safe distance from the implosion or protected by adequate barricades. One danger is debris from the event reaching people. For structures containing hazardous materials, demolition procedure will require the removal of the hazardous materials prior to the implosion. Release of the materials may create additional hazards to surrounding areas and nearby people.

There must be protections if a container might experience implosion due to a process failure. That may include changes in the process design and components or in the structural elements. The goal is to reduce or eliminate risks. Risks may involve process damage and interruption. Risks may involve hazards associated with released process materials or damage to surrounding structures or containers.

EXERCISES

1. An industrial plant is 750 ft wide (along the south and north) and 350 ft deep. It is located on a rectangular lot that is 1750 ft wide (along the south and north) and 1500 ft deep. The lot is bordered on the south by a highway, on the west by a rail line (passenger service), on the east by a residential area and the north by an uninhabited flood plain of a stream. The plant sets back 150 ft north of the highway to provide a parking lot and is offset 250 ft from the west lot line for a shipping and receiving area. Fifteen pounds of explosives are to be used daily in the plant and a 60-day supply is to be maintained at the site. Prepare a layout of the site and using the American Table of Distances, show which areas on the site can be used for
   (a) a daily-use magazine
   (b) a 60-day supply
2. Cinnamon dust has an ignition sensitivity of 2.5 and an explosion severity of 2.3. What is its explosibility index?

REVIEW QUESTIONS

1. Briefly describe each class of explosion in the following list. Note any unique characteristics for each class.

(a) combustion explosion
(b) deflagration
(c) detonation
(d) condensed phase detonation
(e) combustion explosion of a gaseous or liquid fuel in an enclosure
(f) combustion explosions for dust in an enclosure
(g) BLEVE
(h) explosions of pressure vessels containing non-reactive materials
(i) unconfined vapor cloud explosions
(j) deflagrations of mists
(k) chemical reactor runaway
(l) nuclear reactor runaway or nuclear detonations

2. What are the three main causes of damage and injury from explosions?
3. Describe factors that contribute to the occurrence and severity of dust explosions.
4. What three indices are used to characterize the explosion hazard of dusts?
5. What controls help prevent explosions?
6. What controls reduce damage resulting from explosions?
7. What is the general name for the international standard for transport of hazardous materials?
8. In the international system for hazardous materials transport, there are several groups of explosives. How are the groups named? How many groups are there in the classification scheme?
9. What are the hazards of explosives?
10. What controls reduce the hazards of explosives?
11. What causes implosions?

NOTES

1 http://er.jsc.nasa.gov/seh/explode.html; www.history.com/topics/challenger-disaster/videos/engineering-disasters—challenger

2 www.youtube.com/watch?v=XDLkMDJXl_0

3 www.military.com/video/explosions/blast/30000-gallons-of-propane-explodes/1231135923001/

4 www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Chernobyl-Accident/

5 www.pddoc.com/tmi2/kemeny/

6 http://scs.org/upload/documents/conferences/autumnsim/2012/presentations/dmms/15_Final_Submission.pdf

7 www.scs.org

8 *NFPA 67, Guide on Explosion Protection for Gaseous Mixtures in Pipe System*.

9 NFPA 68, *Standard on Explosion Protection by Deflagration Venting*.

10 NFPA 69, *Standard on Explosion Prevention Systems*.

11 49 CFR 173.50, Class 1.

12 49 CFR 173.52, *Classification Codes and Compatibility Groups of Explosives*.

13 49 CFR 173.53, *Provisions for Using Old Classifications of Explosives*.

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CHAPTER 18

HEAT AND COLD

18-1 INTRODUCTION

There are two primary kinds of safety considerations for heat and cold. One involves the thermal conditions in which people live, work, and play. The other involves contact or near contact with hot or cold objects or materials that leads to damage of human tissues. This chapter will discuss both kinds of conditions. Thermal injuries and illnesses are more common from exposure to heat, high temperatures and contact with hot objects. Injuries and illness from exposure to cold and cold objects are less frequent, but can occur.

Humans tolerate a limited range of thermal environments. At one extreme there is excessive cold and low temperatures. At the other, there is excessive heat and high temperature. Only a narrow region in the middle is thermally comfortable. In most indoor environments, the goal is to provide comfortable thermal conditions. It is not possible to control the outdoor conditions very much. The farther thermal conditions deviate from the region of comfort, the greater the likelihood of injury and the faster injury will occur.

Humans, like other warm-blooded animals, have internal thermal regulatory systems. To be comfortable, the rate at which the body produces metabolic heat must balance with heat lost to the surrounding environment. If one loses heat too quickly, one becomes cold. If one loses heat too slowly or if the environment adds heat to the body, one becomes hot. The human body has limited means for adjusting the rate of heat loss. Sweating can increase the rate of cooling. Increased blood flow near the skin can also affect heat loss a little. To slow heat loss, the body may reduce peripheral blood flow and produce shivering.

The rate of heat transferred to the environment from the body can lead to certain heat and cold injuries and illnesses.

Contact with hot or cold objects can also cause injuries to skin and other tissues. In some cases, mere proximity to heat sources and very hot environments can lead to burns. Contact with very cold objects and materials can also cause injury and tissue damage. Protection from extreme conditions is essential.

18-2 HEAT TRANSFER

To understand how exposure to hot or cold environments can lead to injuries and illness, one must have a general understanding of heat transfer principles.

Heat exchange between the body and the environment primarily involves convection, radiation, and evaporation. Conduction is another mode of heat transfer but it is of little significance in air environments. However, in an underwater environment, conduction is the dominant mode of heat transfer. Conduction is also important when the body contacts an object of extreme temperature.

For whole-body heat exchange in air, metabolic heat produced M must balance with the loss to the environment through convection C, radiation R and evaporation E. A simple expression for heat exchange between the body and the environment is

$$M \pm C \pm R - E = \mathrm{O} \tag{18-1}$$

There are some additional, but small factors involved in a complete whole-body heat exchange equation. For example, the body's mass can gain or lose some heat through storage. An increase or decrease in normal body temperature is a measure of the change in stored heat. A precise heat balance equation for whole-body heat exchange would also include an expression for changes in body mass and the resultant heat gain or loss. Body mass increases through intake of food and drink and decreases through excretion and urination. A precise balance would include an expression for peripheral blood flow and an expression for evaporative loss through respiration. It would also recognize that the body is seldom in a steady-state condition. A person's activity and the resulting heat produced by metabolism change frequently. Changes in blood flow and sweating occur often. The heat balance equation needs small adjustments for different individuals.

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The equation would need to account for the effect of clothing, acting as insulation. Nevertheless, Equation (18-1) provides the basis for understanding the heat transfer concept. It allows one to make quantitative estimates of what occurs in a thermal environment. It allows one to compute with reasonable accuracy whether an environment is likely to cause illness or injury.

Metabolism

The rate of heat produced in the body results from the activity level. Cells in the body burn oxygen and nutrients in performing their functions. The chemical combustion process produces heat. In general, the body is inefficient at converting fuel energy to work. As a result, the body converts most metabolic energy to heat. There is a minimum amount of cellular activity to maintain life. Cells produce more heat with increased activity. The activity of the body determines the total amount of heat produced. During sleep the body of an average person burns about 70–75 kcal/hr and converts it to heat. At the other extreme, during very heavy exercise the body produces 720 kcal/hr or more of heat. Table 18-1 lists typical values of energy expended for various activities.

TABLE 18-1 Metabolic Costs (Oxygen Consumption) for Selected Activities

Activity	Cost (kcal/hr)
General	
Light work	Up to 200
Moderate work	200–350
Heavy work	350–500
Resting	
Sleeping	70–75
Sitting quietly	80–100
Standing, relaxed	110
Walking, Running	
Walking on the level	
3.2 km/hr	190
4.0 km/hr	230
4.8 km/hr	265
5.6 km/hr	300
6.4 km/hr	350
Running, 11.3 km/hr	810
Work	
At a desk	115
Driving a car	
Light traffic	80
Heavy traffic	190
Sheet metal work	200
Carpentry	230
Truck and automobile repair	250
Welding	180
Shoveling	410
Sweeping floors	235
Cleaning windows	225
Sawing wood by hand	480
Recreation	
Volleyball	210
Tennis	425
Swimming	400–550
Dancing, moderately	150
Basketball	515

Source: Adapted from C. F. Conzolazio, R. E. Johnson and L. J. Pecora, *Physiological Measurements of Metabolic Functions in Man*, McGraw-Hill, New York, 1963.

Convection

Convection is the transfer of heat by movement of air over the surface of a body. One empirically derived equation for convective heat transfer between a human body and the environment in warm-to-hot environments is

$$C = 1.0\, V^{0.6}(T_a - T_s) \qquad (18\text{-}2)$$

where

C = convection heat transfer (kilocalories per hour)
V = air speed (meters per minute)
T_a = air temperature, dry bulb (degrees Celsius)
T_s = skin surface temperature (degrees Celsius)

This is an approximation and, although this equation may not be accurate for all thermal conditions, it helps us understand the convective component in Equation (18-1). Equation (18-2) assumes an average surface area for the human body of 1.8 m^2. For more precise calculations, the body surface area value needs greater precision and adjustment for the effect of clothing.

In Equation (18-2), note which parameters affect convective heat transfer. One is air speed. The other is the temperature difference between skin and air temperatures.

From Equation (18-1), note that convection C can be positive or negative and add or remove heat from the body. Convection will remove heat (see Equation (18-2)) when the air temperature is lower than that of skin. Convection will add heat when the air temperature is greater than that of the skin. If convection adds heat, other heat transfer methods must remove heat to maintain a constant body temperature and prevent heat-related injury or illness.

Air speed affects the convection heat transfer rate. Whether convection adds or removes heat, a fourfold increase in air speed will about double the rate of heat

transfer. Note that simply increasing air speed does not always provide more cooling. Having a fan blow air over the body when the air temperature is higher than skin temperature actually adds heat to the body by convection. As noted later, air speed also affects the rate of evaporative heat loss. When the air temperature is higher than the skin temperature, increasing air speed may increase cooling from evaporation sufficient to equal or exceed the increase in convection heat transfer.

The temperature of the skin is not constant with time and is not uniform over the entire body surface. Vasoconstriction and vasodilation influence cutaneous blood flow and skin temperature. Air temperature, too, affects the skin temperature. Equation (18-2) requires a single estimate of skin temperature. For heat stress conditions, Equation (18-2) uses a value of 35 °C.

Radiation

The body exchanges heat with its surroundings through radiation. Radiation involves the geometric relationship between the surfaces of two bodies. The surface of one body must be able to "see" the other surface to create an exchange of radiant energy between them. Thermal radiation is highest for wavelengths in the infrared region. However, air is essentially transparent for infrared radiation. Air is not important in most radiation heat transfer situations.

Radiative heat transfer between two bodies is a function of the fourth power of the absolute temperature of the surfaces involved. To simplify the computations for warm-to-hot environments, an approximation used for radiative heat transfer from the human body is

$$R = 11.3(T_w - T_s) \tag{18-3}$$

where

R = radiation (kilocalories per hour)
T_w = mean radiant temperature of the solid surroundings (degrees Celsius)
T_a = skin surface temperature (degrees Celsius)

Equation (18-3) is accurate for a limited range of thermal conditions. However, Equation (18-3) helps in understanding the radiative heat transfer component of Equation (18-1).

Like convection, radiation can add heat to the body or remove it. The key is the difference in temperature between the skin and the surrounding surfaces. If the mean radiant temperature of the surrounding surfaces (usually walls) is higher than the skin temperature, The body will gain heat. If the skin temperature is greater than the mean radiant temperature of the surrounding surfaces, the body will lose heat. The direction of heat transfer in Equation (18-3) will determine whether to use a positive or negative sign for R in Equation (18-1). Equation (18-3) requires a single estimate of skin temperature. For heat stress conditions, 35 °C is the commonly used value.

Evaporation

Humans can sweat as a means to cool the body. Sweat glands in the skin secrete sweat, which is primarily water containing some dissolved salts. The hypothalamus in the brain controls sweat gland activity. There is considerable variation in sweat rates among individuals. The level of physical activity and other factors influence the number of sweat glands active at one time. Sweat increases as the thermal regulation system in the body seeks increased cooling to remove heat. Cooling results from the change in state from liquid to vapor as the water evaporates from the skin.

The maximum amount of cooling achievable through sweating is a function of air speed and the ability of the surrounding air to accept additional moisture. An estimate of maximum cooling capacity for warm-to-hot environments is

$$E_{max} = 2.0V^{0.6}(PW_s - PW_a) \tag{18-4}$$

where

E_{max} = maximum evaporative heat loss (kilocalories per hour)
V = air speed (meters per minute)
PW_s = vapor pressure of water at skin temperature (millimeters of mercury)
PW_a = vapor pressure of water at air temperature (millimeters of mercury)

Equation (18-4) helps us understand evaporative heat loss, even if it may not be accurate for all thermal conditions. Note that the two parameters involved are air speed and vapor pressure difference between the air and skin. The most important of the two is the vapor pressure difference. Also note that evaporative cooling works in one direction only, removing heat.

In hot, humid conditions, the vapor pressures in air and at the skin surface are nearly the same. Such conditions limit cooling through evaporation of sweat. In hot, dry environments the difference in vapor pressures is large and evaporation is rapid. In hot, dry conditions the limiting factor may be the maximum rate of sweat production.

A psychrometric chart provides vapor pressure and relative humidity data. One must measure the dry-bulb temperature and wet-bulb temperature to enter the chart to

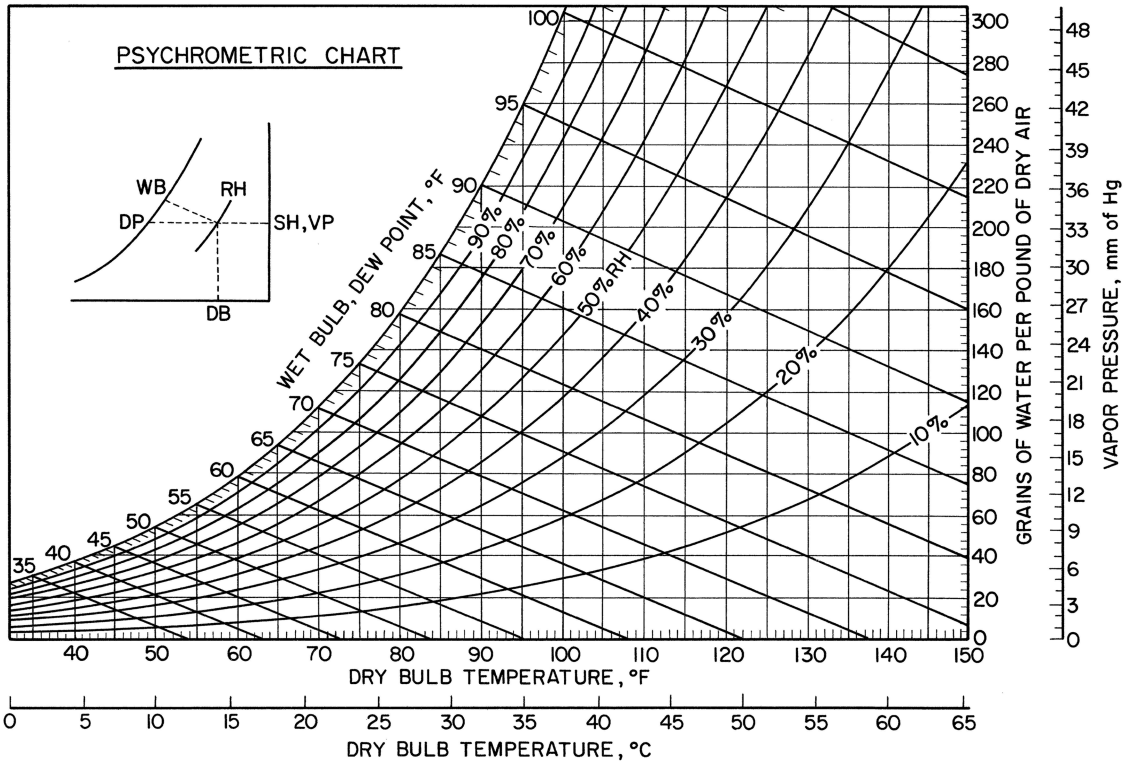


Figure 18-1. Psychometric chart.

determine vapor pressure. An alternative is knowing the dry-bulb temperature and relative humidity.

Figure 18-1 is a psychrometric chart. To find the relative humidity, follow the lines for a dry-bulb temperature and a wet-bulb temperature to the point of their intersection. Then read or interpolate the relative humidity from the percent relative humidity lines. For example, the 80 °F dry-bulb temperature and the 75 °F wet-bulb temperature lines intersect at the 80% relative humidity line.

Also note that one of the units along the right side is vapor pressure in mm Hg. From an intersection of a dry-bulb temperature and a web-bulb temperature, one can move horizontally to the right to find the vapor pressure. For an 80 °F dry bulb and a 75 °F wet bulb, the vapor pressure is about 21 mm Hg.

Clothing and Insulation

Clothing slows the rate of heat transfer between the body and the environment. In most cases clothing provides insulation to slow the loss of heat from the body. Various fabrics have different insulation values.

Aluminized, reflective clothing may help slow heat transfer. The amount depends on how clothing incorporates the reflective material. When applied on the outer surface, reflective material can slow radiant heat gain from intense radiant sources. Such sources are those of a fire or open flame operation. Certain firefighting and hot work fabrics use this feature. When applied on the inner surface, reflective material can help retain body heat. Some gloves and other cold weather clothing use this feature.

Fabrics that inhibit moisture loss may eliminate evaporation as a means of heat loss when the air inside the fabric becomes saturated with moisture. Equipment, such as vortex coolers and water-cooled helmets or underwear can remove heat from the "microclimate" inside some types of clothing assemblies.

In some conditions, the goal for a fabric is releasing sweat to the surface and minimizing insulating properties. Such fabrics find uses in hot environments.

Heavy or restrictive clothing may add to thermal problems by increasing the metabolic work required just to move the clothing. That is in addition to the work involved in an activity itself. An activity that is considered light work may become heavy work when someone wears special or heavy clothing. An example is a fireman's coat. It increase the work load and potential for heat injury or illness while providing insulation from the heat of a fire or hot materials.

Special clothing may insulate a person from local heat transfer problems, such as burns from hot objects and hot particles or frost injury from very cold objects. Restrictive

TABLE 18-2 Insulation Value of Different Clothing Assemblies

Clothing Assembly	I_{cl} (clo)
Nude	0
Shorts	0.1
Typical Tropical Clothing Assembly:	
Shorts, open-neck shirt with short sleeves, light socks and sandals	0.3–0.4
Light Summer Clothing:	
Long light-weight trousers, open neck shirt with short sleeves	0.5
Light Working assembly:	
Athletic shorts, woolen socks, cotton work shirt (open-neck) and work trousers, shirttail out	0.6
U.S. Army Fatigues, Men's:	
Light-weight underwear, cotton shirt and trousers, cushion sole socks and combat boots	0.7
Typical Business Suit	1.0
Typical Business Suite plus cotton coat	1.5
Light Outdoor Sportswear:	
Cotton shirt, trousers, T-shirt, shorts, socks, shoes and single ply poplin (cotton blend) jacket	0.9
Heavy Traditional European Business Suit:	
Cotton underwear with long legs and sleeves, shirt, woolen socks, shoes, suit including trousers, jacket and vest	1.5
Heavy Wool Pile Assembly:	
Polar weather suit	3–4

Source: From P. O. Fanger, *Thermal Comfort*, Danish Technical Press, Copenhagen, 1970.

clothing may make wearers less agile. Loose clothing is more likely to get caught in equipment and machines.

A clo is the unit of measure for the insulation value of a clothing assembly. There are methods for determining the clo values of clothing assemblies. Controlled laboratory procedures involve placing a clothing assembly on a heated manikin and making measurements. Table 18-2 provides clo values for some clothing assemblies.

An estimate of the amount of clothing required for protection in cold environments is

$$I_{req} = \frac{13.3(T_s - T_a)}{M} \tag{18-5}$$

where

I_{req} = clothing insulation required (clo)
T_s = skin surface temperature (degrees Celsius)
T_a = air temperature (degrees Celsius)
M = metabolic rate (kilocalories per hour)

Equation (18-5) assumes a body surface area, SA, of 1.8 m^2 as an average value. Accuracy may require adjustments in the body surface area value. The empirical equation

TABLE 18-3 Approximate Insulation Value of Air Film at Different Air Speeds

I_f (clo)	Air Speed (km/hr)
0.7	Calm
0.5	1.8
0.3	6.0
0.1	16.1
Negligible	65.0

of DuBois allows computing the body surface area:

$$SA = 71.84 \times 10^{-4}(W^{0.425})(H^{0.725}) \tag{18-6}$$

where

SA = body surface area (square meters)
W = weight of the person (kilograms)
H = height of the person (centimeters)

Skin temperature for comfort in the cold is about 33 °C. This value provides an average skin temperature in Equation (18-5). Exposed skin would have a lower temperature.

The available insulation is made up of the insulation value of the clothing assembly plus a film of still air at the outer surface of the clothing,

$$I_a = I_{cl} + I_f \tag{18-7}$$

where

I_a = available insulation (clo)
I_{cl} = insulation value of a clothing assembly (clo)
I_f = insulation value of the film of still air at the clothing surface (clo)

The film of still air and its insulation value diminish rapidly as air speed increases. Table 18-3 lists some typical insulation values for the film of air at different air speeds.

One can estimate the insulation needed for a known environment and activity. One can combine Equations (18-5) and (18-7) and solve for I_{cl}:

$$I_{cl} = I_{req} - I_f \tag{18-8}$$

18-3 THERMAL MEASUREMENT

Before determining how hazardous a thermal environment is, one must make measurements of conditions. An assessment may involve several instruments. Some measurements in

English units may need conversion to metric units or vice versa.

Air Temperature

The simplest device for measuring air temperature (dry bulb) is a thermometer. There are also battery-powered, portable instruments with analog or digital readouts. The sensors for these instruments are often thermocouple or thermistor devices.

Humidity

Relative humidity is difficult to measure directly. There are accurate, direct reading humidity instruments. An alternative and precise method involves obtaining both dry-bulb and web-bulb temperature readings and using a psychrometric chart to find the humidity level.

A standard air temperature thermometer provides dry-bulb readings. Wet-bulb temperatures involve the use of a dry-bulb thermometer and a clean, wet sock placed over the bulb of the dry-bulb thermometer. Then the bulb of the thermometer must move rapidly through the air or air moved rapidly over the bulb. The air motion causes evaporative cooling for the thermometer bulb. The wet-bulb temperature reading will be lower than a dry-bulb reading.

To obtain the two temperature readings, one can use a sling psychrometer. This is a special kit that holds two thermometers (one wet-bulb and one dry-bulb) on a sling. A user hangs onto a handle and whirls them around. Another device holds the two thermometers and sets on a surface. A built-in fan provides moving air to cool the wet sock of the wet-bulb thermometer. Again, the readings require use of a psychrometric chart to determine relative humidity.

An index discussed later is the wet-bulb globe temperature (WBGT). When making wet-bulb readings for WBGT, the wet-bulb thermometer must be stationary and not involve moving air.

Mean Radiant Temperature

Obtaining an accurate measure of the mean radiant temperature of surrounding surfaces requires a complicated procedure. One must measure the temperature and area of each surface and then compute their average. This is a rather cumbersome and often impractical approach.

An alternative is to use a black globe thermometer. It provides a good estimate of the mean radiant temperature. A dry-bulb thermometer or other dry-bulb sensor located at the center of a sphere measures the temperature inside the spherical globe. The sphere should be a 15 cm (6 in.) diameter hollow copper sphere painted matte black on the outside. The globe must remain in a fixed location in an environment for about 25–30 min. By then the temperature inside the globe will have reached a steady-state condition. The rate at which the globe absorbs radiant energy balances with the convective heat loss from the sphere's outside surface to form a steady state.

Air Speed

There are many different types of anemometers for measuring air speed. Desirable features for assessing thermal conditions are portability, durability, and ruggedness. Also important are having a nondirectional sensor, sensitivity at low speeds, and fast response time. Instruments with a heated sensing device (heated thermocouple, heated thermistor, or hot wire) provide these features.

Body Temperature

For most hot and cold environments there is no need to monitor the body temperature. In extremely hot or cold environments and in confined areas or those isolated from assistance, core temperature monitoring may be necessary to ensure that body temperatures remain within pre-established upper or lower limits. If the body temperature reaches a limit, there is time to remove a person from stressful conditions before severe physiological damage occurs. If direct leads from a person to a temperature instrument restricts activities, it is better to use temperature devices with telemetry and distant readout displays.

Another problem is intolerance of core temperature sensors by the wearer. Oral temperature is not very accurate and reliable for core temperature assessments. Rectal probes provide more accurate readings, but are less tolerable. A more acceptable sensor is a tympanic sensor. It has a thermistor bead or small thermocouple placed in the ear canal against or very near the eardrum and held in place by a custom-molded ear plug. Tympanic temperature closely follows changes in core temperature. The preferred readout display is a digital one.

18-4 HEAT

Hazards

There are two kinds of effects of high temperatures and hot environments on humans: heat illnesses and burns. Excessive exposures to hot environments are the main causes of heat illnesses. Burns result from contact with hot materials or surfaces or from excessive irradiance of the skin by heat-producing wavelengths of radiant energy.

CASE 18-1

18-1a

August 2003, Europe. Studies have identified that temperatures reach significant levels above or below normal in pockets around the globe for a few weeks or months. The pockets of change are not always in the same locations.

During June, July, and August 2003, a major portion of Europe experienced an unusual heatwave. Many parts of Europe do not have air conditioning. Governments attributed many deaths to the hot conditions.[a] Below is a list of the estimated deaths by country:

Italy	20,089
France	19,490
Spain	15,090
Germany	9,355
Portugal	2,696

[a]www.statista.com/statistics/267708/number-of-deaths-globally-due-to-heat-or-cold-waves

18-1b

June 18, 2015, Karachi, Pakistan. A week-long heatwave killed 1,233 people in this port city. Authorities reported that doctors at all of Karachi's hospitals treated about 65,000 patients with heatstroke. More than 1,900 patients remained under treatment for heat-related illnesses. Temperatures reached 113 degrees F.[b]

[b]http://tribune.com.pk/story/911335/heatwave-death-toll-in-karachi-crosses-1200-health-department/

Heat Illnesses

People living or working in hot environments may experience heat illnesses. Often employers have ways to manage the work, the work schedule and sometimes the environmental conditions. Employers may also provide special clothing that insulates workers or provides cooling.

A more devastating situation occurs when environmental conditions affect a large, public population. Government agencies may need to help minimize the public danger through shelters with cooler and safer conditions, providing cooling stations with drinking water or other means of reducing danger from hot conditions.

Excessive exposure to hot environments can result in behavioral changes, an elevated core temperature of the body, failure of the temperature regulatory mechanism, circulatory failure, depletion of water and body salts, and inflammation of sweat glands. These and other symptoms characterize the following heat illnesses.

Hyperthermia Hyperthermia is an elevated body temperature. Someone may contract an illness that causes the body temperature to rise above the normal 98.6°F oral temperature. The elevated body temperature is hyperthermia, but the common term during an illness is fever. If a hot environment increases the body temperature, that is also hyperthermia.

Heat Stroke or Sunstroke This illness is primarily a failure of the thermal regulatory mechanism in the body. A characteristic of heat stroke is termination of sweating. The skin becomes hot and dry. The body temperature rises and mental confusion, loss of consciousness, convulsions, or coma may result. Victims need immediate and rapid cooling. Delays in treatment can be fatal.

Sunstroke is heatstroke resulting from excessive exposure to the sun.

Heat Hyperpyrexia This illness is a milder form of heatstroke in which there is partial rather than complete failure of sweating. Some sweating may continue to occur. Other heatstroke manifestations are also less severe.

Heat Syncope Standing individuals not acclimatized to hot environments may faint. That results when the body redistributes blood to peripheral tissue and reduces the blood flow to the brain. The treatment for this condition

is removal to a cooler location and having a victim lie down.

Heat Exhaustion or Heat Prostration Excessive loss of water through sweating and inadequate circulation may result in fatigue, nausea, headache or giddiness. Cold clammy skin characterizes this condition. Urine becomes concentrated and is low in volume. The primary cause is inadequate water intake during exertion in hot environments. Treatments include moving a victim to a cooler location, encouraging rest, and replacing lost body fluids.

Heat Cramps Painful muscle cramps during or following exertion in hot environments characterize this illness. Excessive loss of body salts during sweating causes the cramps. Treatment involves replacing depleted body salts. Commercial fluids, sometimes called sports drinks, containing chemicals lost through sweating, are useful.

Heat Rash Some call this disorder prickly heat. These are small, blister-like eruptions on the skin that have a prickly sensation during heat exposure. Sweat glands become plugged and the sweat cannot escape. Inflammation results. Treatment involves keeping skin dry and avoiding heat exposure during treatment.

Heat Fatigue Some individuals, particularly those not acclimatized, may exhibit reduced performance of sensorimotor, mental and vigilance tasks when exposed to heat. Other behavioral changes (reduced work effort, reducing clothing, or seeking cooler conditions) may also result as people experience discomfort and physiological strain from hot environments. In some cases acclimatization and training may reduce behavioral effects to some extent.

Indices of Heat Stress

The idea of thermal comfort is based on subjective evaluations of thermal environments. Individuals rate conditions as cold, cool, neutral, warm, or hot. An early thermal comfort scale was the Effective Temperature Scale. More recent studies led to a standard for defining thermal comfort conditions by ASHRAE. Standard 55-2013[1] is the most recent edition, but updates occur every few years.

Heat stress involves hot environments outside the comfort zone. Heat stress conditions in the physical environment are those resulting in physiological changes, such as blood flow, internal body temperature, and sweating. These changes are indicators of heat strain, a term referring to the physiological changes brought on by heat stress conditions of the physical environment.

There are several heat stress indices that predict whether exposures to hot environments will result in excessive heat strain. Two commonly used indices are the heat stress index (HSI) and the wet-bulb globe temperature index (WBGT). The heat stress index is probably a more accurate predictor of heat strain. However, the instrumentation and calculations required for a WBGT assessment are much simpler. Because of its simplicity for field use, WBGT is the index recommended by NIOSH and ACGIH (American Conference of Governmental Industrial Hygienists). Both HSI and WBGT decision tables apply to 8-hr exposures. OSHA also recommends use of WBGT.[2]

The National Weather Service developed a third index, the heat index, as a simple way to help people decide about exposures in hot and humid conditions.

Heat Stress Index The HSI compares two theoretical sweat evaporation conditions. HSI compares the amount of sweat that must be evaporated to balance the heat loss equation (Equation (18-1)) for a given set of environmental conditions to the maximum amount of sweat that can actually evaporate for those conditions:

$$HSI = E_{req} \times 100 / E_{max} \tag{18-9}$$

where

HSI = a dimensionless index number
E_{req} = evaporative heat loss required (kilocalories per hour)
E_{max} = maximum evaporative heat loss (kilocalories per hour)

One can compute E_{req} by combining Equation (18-1) with Equations (18-2) and (18-3). One can compute E_{max} using Equation (18-4). In Equations (18-2) and (18-3), the assumed skin surface temperature is 35 °C.

Table 18-4 provides implications for various values of HSI. One can use Table 18-4 and HSI values to decide if an environment is safe or there is a need for protective actions. There may be environmental conditions that result in values for HSI greater than those explained in Table 18-4. Such values indicate that conditions are excessive for everyone. Values less than those in Table 18-4 indicate cold conditions to which HSI does not apply.

Wet-Bulb Globe Temperature Index Researchers developed the WBGT index as a simple-to-use method for determining if military troops were likely to suffer from heat illnesses in hot environments. The WBGT index requires only two or three measurements: wet-bulb (static) temperature (WB), dry-bulb temperature (DB), and globe temperature (GT). One can compute WBGT values from one of two equations, depending on the presence of a solar load.

$$\text{WBGT} = 0.7\text{WB} + 0.2\text{GT} + 0.1\text{DB (with a solar load)} \tag{18-10}$$

$$\text{WBGT} = 0.7\text{WB} + 0.3\text{GT (with no solar load)} \tag{18-11}$$

TABLE 18-4 Heat Stress Index Implications[a]

HIS	Implications of 8-hr exposures
−20	Mild cold strain.
−10	
0	No thermal strain.
+ 10	Mild to moderate heat strain. Small
20	decrements in motor, mental and vigilance
30	tasks. Little effect for performance of heavy physical work.
40	Severe heat strain. A threat to health unless
50	workers are physically fit. Unacclimatized
60	workers need a break-in period. Medical selection of workers desirable to screen out those with existing physiological impairments.
70	Very severe heat strain. Only a small
80	percentage of the population can be expected
90	to qualify for this work. Special protective measures needed to prevent heat illnesses from occurring.
100	The maximum strain tolerated daily by fit, acclimatized young men.

[a]Adapted from Belding and Hatch, "Index for Evaluating Heat Stress in Terms of Resulting Physiological Strains," *Journal of American Society of Heating and Ventilating Engineers*, 27: 129ff (1950).

When there is a sequence of different thermal environments during an 8-hr period, one can compute an average WBGT value from

$$\mathrm{WBGT_{avg}} = (\mathrm{WBGT_1} \times \mathrm{t_1}) + (\mathrm{WBGT_2} \times \mathrm{t_2}) + \ldots + (\mathrm{WBGT_n} \times \mathrm{t_n})/\mathrm{t_1} + \mathrm{t_2} + \ldots + \mathrm{t_n} \quad (18\text{-}12)$$

The American Conference of Governmental Industrial Hygienists (ACGIH) establishes permissible heat exposure threshold limit values (TLVs). OSHA also references these TLVs.[3] From a knowledge of the metabolic activity (see Table 18-1) and computed WBGT values, one can decide from the TLVs if there is a need for work adjustments. The TLVs assume a person is wearing light summer clothing, is acclimatized, has adequate water and salt intake, and has a deep-body temperature at or below 38 °C. The TLVs assume the thermal conditions in a rest area are about the same as the work area.

Heat Index The heat index has come into common use. During the heat of the summer, most local weather reports include the heat index along with the actual dry-bulb temperature. Another name for the heat index is the apparent temperature. It represents what the temperature feels like to the human body when air temperature combines with relative humidity.

There are two options for determining heat index. One is to know the air temperature and the relative humidity in percent and then find the heat index value in a table. Table 18-5 is the National Weather Service Heat Index Table.[4]

Note that Table 18-5 applies to shady locations. If someone is in a sunny location, the heat index value may be up to 15 °F higher.

The other option is to compute heat index values from an equation derived from multiple regression analysis.

$$\begin{aligned}\text{Heat Index} = {} & -42.379 + 2.04901523T + 10.14333127R \\ & - 0.22475541TR - 6.83783 \times 10^{-3}T^2 \\ & -5.481717 \times 10^{-2}R^2 + 1.22874 \times 10^{-3}T^2R \\ & + 8.5282 \times 10^{-4}TR^2 - 1.99 \times 10^{-6}T^2R^2\end{aligned} \quad (18\text{-}13)$$

where

T = air temperature (°F)
R = relative humidity (percent)

One can decide about exposures from the Heat Index Chart and Tables 18-6 and 18-7.

Controls

There are several ways to reduce or eliminate heat stress and the resulting thermal illnesses or injuries. The approaches include controlling the source, modifying the environment, adjusting the work or activity, providing protective equipment, and meeting physiological and medical needs of workers.

One can also divide these protections between engineering controls and administrative controls. Engineering controls may modify the hot conditions or create shaded areas suitable for rest in work–rest cycles. Administrative controls may include providing protective clothing, a good supply of drinking water to minimize dehydration, establishing suitable work–rest plans, and training workers on heat stress conditions and detection of heat strain indicators.

Controlling the Source Keeping heat sources and hot surfaces away from occupied areas will reduce the chance of heat buildup or contact. For example, placing an oven in a separate area can reduce the heat added to a work area. Insulation applied to a hot surface or object will prevent air from becoming hot and people from coming into contact with the hot surfaces. Not only is the hazard reduced, but insulation conserves energy also.

In some operations, materials and processes have temperatures that are higher than necessary. Reducing temperatures may reduce or eliminate thermal hazards.

Modifying the Environment The physical parameters involved in heat stress are air temperature, air velocity, mean radiant temperature, and vapor pressure. When one cannot

TABLE 18-5 Heat Index Chart[a] (Air Temperature and Relative Humidity)

Relative Humidity (%)	Air Temperature (°F)															
	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure and/or Strenuous Activity
Caution Extreme Caution Danger Extreme Danger

[a] http://www.crh.noaa.gov/images/unr/preparedness/heatindex.pdf

modify these parameters at their sources, ventilation may reduce heat stress. Ventilation is the process of supplying air from some location other than the stressful environment. Ventilation may be a limited solution. Remember that the key is the temperature difference between air temperature and ventilation air. The ventilation air supplied may be similar to the heat stress environment and have little cooling value as seen in the discussion of heat transfer equations. One must make measurements of the supplied air and its thermal conditions to determine how beneficial it can be. If ventilation is not effective, a final control is cooling air with air conditioning equipment. Chapter 25 discusses ventilation in detail.

For environments with intense radiant sources, shielding may reduce the radiation reaching a person. Radiant energy travels in a straight line. Also, radiant energy does not heat air directly. In other cases, one can reduce radiant energy for a person by increasing the distance between a person and the radiant source. Radiation intensity diminishes with the square of the distance.

TABLE 18-6 Heat Index and Effects on a Human Body[a]

Classification	Heat Index	Effect on the body
Caution	80 to 90 °F	Fatigue possible with prolonged exposure and/or physical activity
Extreme Caution	90 to 103 °F	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	103 to 124 °F	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	125 °F or higher	Heat stroke highly likely

[a] https://www.osha.gov/SLTC/heatillness/heat_index/

TABLE 18-7 Heat Index, Risk Level and Protective Measures

Heat Index	Risk Level	Protective Measures
<91 °F	Lower (Caution)	Basic heat safety and planning
91 to 103 °F	Moderate	Implement precautions and heighten awareness
103 to 115 °F	High	Additional precautions to protect workers
>115 °F	Very High to Extreme	Triggers even more aggressive protective measures

TABLE 18-8 Permissible Heat Exposure Threshold Limit Values[a] (WBGT readings in °C/°F)

	Work Load		
Work- Rest Regimen	Light	Moderate	Heavy
Continuous work	30.0/86	26.7/80	25.0/77
75% work–25% rest, each hour	30.6/87	28.0/82	25.9/78
50% work–50% rest, each hour	31.4/89	29.4/85	27.9/82
25% work–75% rest, each hour	32.2/90	31.1/88	30.0/86

[a]*OSHA Technical Manual* (OTM), Section III: Chapter 4 (Refer to publication for implementing details.) www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html

Barrier guards will prevent people from coming into contact with hot surfaces or getting close to operations where there is hot material.

Adjusting Activities It is possible to reduce heat stress by modifying activities. By making work easier, using materials handling equipment or power tools, it is possible to reduce the metabolic heat generated.

Another way to adjust the work is to limit the time of exposure to hot environments. It is also possible to provide adequate periods of rest. Both of these approaches reduce the heat buildup in the body. OSHA recommendations in Table 18-8 offer this approach.

A related approach is to rotate workers through different jobs so only a portion of their work is in stressful environments or involves high energy work that contributes to heat stress. This approach retains the productivity of a work group.

Providing Protective Equipment For hot environments, workers may use water-cooled clothing (helmets, underwear, and full uniforms). Most air-cooled clothing relies on air lines and vortex devices for cooling. Some may use refrigerant systems to create cooling. The former systems are usually less expensive and may provide sufficient cooling capacity in some environments. Cooling of full suits may require separate, uncontaminated breathing air. Pressurized air for cooling may not be safe for breathing.

In environments with intense radiation, reflective clothing may help reduce heat loads. In addition, for certain radiant energy sources, there may be a need for protective eye wear that reflects or filters harmful wavelengths. There is a wide variety of aluminized fabrics. Selection depends on the kind of thermal exposure and other factors.

There are at least two types of reflective suits for fire fighters. One is a proximity suit. The other is an entry suit. Proximity suits allow wearers to approach a heat source. Entry suits have much more insulation to prevent contact burns and reduce the rate of heat buildup inside the suit.

Full, heat-protective garments usually require internal cooling. Otherwise the heat builds up inside the suit in a short time. Without cooling systems, full suit wearers will probably need time limits to prevent excessive heat buildup inside the suit. The wearers must remain in the heat stress conditions for no longer than the established time limit.

Protective clothes may solve some heat problems and add to others. Here are some examples.

- In selecting protective clothing, one should remember that protective clothing does not remove the hazard, it only protects the wearer from the hazard while worn.
- Use of protective clothing depends on the wearer's cooperation for effectiveness.
- Wearing protective clothing will increase the metabolic rate for the activity. The metabolic work required to do physical work while wearing heavy clothing can be significantly higher than for the same activity without the clothing.
- Heat and moisture buildup inside a garment can create a hazardous local thermal environment that is not present outside the garment.

Insulated materials will help prevent burns from contact with hot objects, from splashes of hot material, or from heat transfer by conduction. Gloves, pads, aprons, pants, chaps, and other kinds of insulated clothing items help prevent burns. Most of these protective items come in fabrics or materials with a variety of thermal characteristics.

CASE 18-2

May 30, 2002, Michigan. A landscape mowing assistant collapsed about 3:00 pm. He was part of a two-person team that completed mowing, trimming and cleanup for residential lawns. EMS personnel transported him to a hospital where he was pronounced dead with a recorded rectal temperature of 107.6 °F (42 °C). An autopsy report also showed he had two prescription drugs present in his blood. One comes with a warning related to conditions that may contribute to elevated core body temperature. The autopsy report listed hyperthermia as the cause of death.[a]

[a]www.cdc.gov/niosh/face/stateface/mi/02mi075.html

Physiological and Medical Controls A primary means for reducing heat strain is ensuring that people replace lost body salts and water. Medical examinations may help identify those who are greater risks for heat stress illness because of age, physical condition, or existing health problems. Administrative procedures may require keeping high risk people out of heat stress environments.

In some activities an acclimatization program may reduce heat stress risks. Workers may gradually increase their level of heat stress conditions and the amount of time in them. The acclimatization may improve to some degree the capacity of individuals to perform in hot environments.

Exposure to extreme environments continuously may require medical monitoring. One aspect of such monitoring is continuously measuring the deep body temperature. There must be someone in place who can get a worker out of the extreme condition if the deep body temperature approaches or reaches 38 °C. In addition, medical monitoring may involve continuous measurement of heart and respiratory rates, and sweat rate. Visual observation may be part of medical monitoring. A worker in an extreme environment should have rescue and recovery equipment. There must be an emergency plan that includes a rescue from danger.

18-5 BURNS

Understanding Burns

The body can remove heat from the skin or other body tissue at a rate determined by blood flow through the tissue. That capability is limited. If heat is added to local tissue through contact with a hot object or materials (conduction), from exposure to sources of high radiant energy (radiation) or from exposure to hot air (convection) at a rate that is greater than the removal rate, the tissue must store the energy. The tissue temperature will rise, resulting in discomfort, pain, or tissue damage. If the heat transfer rate is high, the elevation of local skin temperature can occur in seconds or less.

Human skin has a reflectance ranging from 5% up to 70% for wavelengths in the region from $0.2–2.0 \times 10^{-6}$ m. Skin color affects this reflectance a small amount. Above and below these wavelengths, the skin acts essentially as a black body and absorbs all radiant energy. Radiation in the microwave and infrared range causes heating of tissue.

Burn Classifications

There are several ways to classify burns. One involves the source of tissue damage. A second involves the type of tissue damage. The third considers burn depth. A fourth counts the portion of the body surface affected.

The second and third scheme reflect the structure of the skin. The epidermis is the outer layer of the skin. The dermis is the inner layer containing hair follicles and sweat glands. The tissue below the skin is the subcutaneous region. It contains a network of blood vessels serving the skin.

Burn Sources In most cases people think of a burn as tissue damage from heat or fire. Some medical sources define a burn as tissue damage caused by heat, chemicals, electricity, sunlight, or radiation. Some even include frostbite or contact with cryogenic materials as a burn. Contact with hot or cold liquids and contact with steam can cause burns. Even inhaling heat and smoke from a fire can cause burns to lungs and respiratory tissue. Electricity flowing over or through the body causes a variety of injuries, including thermal damage. Contact with chemicals may produce damage to the skin and other tissues. These chemical injuries are often classified as chemical burns. Contact with very cold, cryogenic liquids can also cause tissue damage similar to that resulting from high temperatures.

Burn Classification by Degree The type of tissue damage provides a long-standing classification for burns. Visual characteristics provide the means for this classification. Most sources use three categories, as shown in Table 18-9. Some have added a fourth category, also listed in Table 18-9.

Burn Depth Classification This classification is very similar to and incorporates the burn classification. The scheme emerged to add medical clarity to the burn classification method. This scheme considers the level of tissue

TABLE 18-9 Burn Classification by Degree

Classification	General Characteristic
First Degree	Damage to the outer layer of skin (epidermis) only. Burn site is red, painful, dry and no blisters. Mild sunburn is one example.
Second Degree	Damage to the outer layer and layer underneath (epidermis and dermis). Burn site is red, blistered, and may be swollen and painful.
Third Degree	Epidermis and dermis destroyed with subcutaneous tissue damaged. Burn site may appear white or charred.
Fourth Degree	Damage to underlying bones, muscles and tendons. There is no sensation in the area since the nerve endings are destroyed.

TABLE 18-10 Burn Depth Classifications

Degree of Burn	Wound Thickness	Characteristics
First	Superficial	Erythema (reddening), pain; partial healing occurs in 5–10 days
Second	Deep	Blisters, pain; partial healing occurs in 2 weeks to 1 month
Third	Full	Skin destroyed, subcutaneous and possibly deeper tissue destroyed, lack of pain; extended period of healing

involved as a way to characterize a burn. Table 18-10 lists characteristics for burn depth classifications.

Extent of Body Surface Burned Another burn classification describes the portion of the body surface area injured. For example, a case description may state that burns occurred over 60% of the body. This refers to the fact that there was some degree of burn on 60% of the skin surface.

Heat and Temperature Related to Burns

The normal internal temperature of the body is about 37.5 °C. A normal skin temperature is about 35 °C in a comfortable environment. Elevating tissue temperatures will produce damage or destruction, depending on the length of time the tissue remains at an elevated temperature.

When the total heat transfer is such that the core temperature of the body becomes elevated for a sufficient length of time, death can result. The surface temperature may not cause pain. An example is immersion in a bath for an extended period at a temperature of 43 °C. People have died from such an exposure in hot tubs.

Local tissue damage will occur when the skin surface temperature is 44 °C or greater. Pain occurs when the temperature reaches 45 °C. Intolerable pain is likely when the skin temperature reaches 46 °C.

Researchers have identified the time required for burns to occur.[5] For example, a surface temperature of skin at 65 °C (150 °F) will produce a burn almost instantly. A skin temperature at 55 °C (130 °F) will create a burn in about 25 seconds. A skin temperature of 50 °C (120 °F) will create a burn in about 3 minutes. Most home water heaters have temperatures set at 120 °F or less to prevent even minor burns from short-term contact.

Figure 18-2 presents the relationship between irradiance of the skin and exposure time that produces pain.

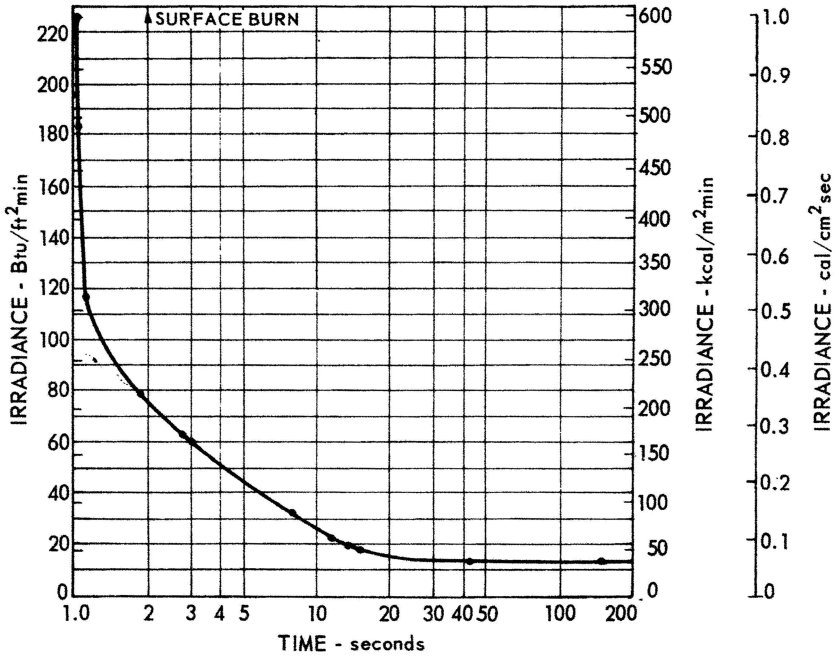


Figure 18-2. Relationship between irradiance and time of exposure for strong pain. (From P. Webb, *Bioastronautics Data Book*, NASA SP3006, National Aeronautics and Space Administration, Washington, DC, 1964.)

CASE 18-3

September 9, 1998, Arkansas. A forest ranger was operating a crawler tractor along with other operators and crawlers to create a fire line about 9 feet wide and about 25 feet from a wild fire in a county forest area. The temperature that day was 87 °F with winds of 8 to 15 mph. The relative humidity was only 18%. The terrain was flat.

The operator at the front of the group saw fire movement toward the other operators. He drove to a safe area, exited his cab and tried to radio an alert to the other operators. His radio failed. He apparently received radiant burns and then walked toward the other operators. His pants were burned away. He had burns to legs, hands, and face. An ambulance took him to a hospital a short distance away. He received treatment for second and third degree radiant burns covering 60% of his body. Several days later he died of complications from the burns.[a]

[a]www.cdc.gov/niosh/fire/pdfs/face9830.pdf

Controls for Burns

Whenever there is a potential for exposure to conditions that may produce burns, there is a need to implement protective strategies. In some cases, engineering controls are necessary. One example is insulating hot surfaces to reduce surface temperatures to levels that will not create burns. Another is providing shields between radiant heat sources and workers.

In some cases administrative controls work best. For example, those working in bakeries around hot pans and ovens need hot pads or gloves that are in good condition. Those handling hot metals need gloves with suitable amounts of insulation to prevent burns. In addition, workers need training, work planning, coordination with others, and operating procedures that minimize the potential for burns.

18-6 COLD

The body has a very limited capacity to adjust to cold environmental conditions. Adjustments in blood circulation may conserve body heat, and shivering increases metabolic heat production slightly.

Hazards

Cold can produce local tissue damage and reduce the core temperature of the body (hypothermia). There are several cold-related illnesses and injuries.

Trenchfoot Trenchfoot can occur when there is exposure for several days to temperatures sensed as cold (but well above freezing), when the skin is moist, and when there is inactivity. The prolonged exposure causes vasoconstriction in the feet and legs. Prolonged cold conditions above freezing lead to vasoconstriction, tissue swelling, and nerve and small blood vessel injury. Initially the skin has a pale appearance accompanied by numbness. Swelling and pain may following the initial paleness. Even after warming feet, numbness may continue for several weeks. Peripheral nerves are most sensitive to these conditions.

Trenchfoot got its name because the disorder was common among WWI troops who stood in cold water and mud in the trenches. Among civilians, trenchfoot can occur among workers exposed to wet conditions or those engaged in hiking and camping.

Immersion foot is a more severe version of trenchfoot. The disorder has occurred among downed pilots and ship evacuees who spend long hours in life rafts.

Chilblains When exposed to the cold, there is congestion of the capillaries. Symptoms involve itching and painful reddening of the skin. Exposed areas, such as fingers, ears, and toes, are more likely to exhibit symptoms.

Cold Urticaria (Hives) In some people coldness in tissue causes release of histamine in tissues. The result is itchy, red blotches in the skin. In some cases an exposure produces the same kind of tissue swelling in other area such as breathing passages. Exposure may also produce other histamine reactions, such as vomiting and rapid heart rate.

Frostbite Frostbite and tissue damage occurs when tissue temperature reaches or goes below the freezing point. The degree of damage depends on the depth of tissue frozen. Mild damage may result if only superficial layers freeze. In frostbite skin is usually white or grayish yellow in appearance. There may be some pain. In many cases a victim is unaware of suffering from frostbite.

Frostnip is the first stage of frostbite. The skin turns pale or red and feels very cold. Prickling and numbness may occur. The second stage is superficial frostbite. Some ice

crystals may form in tissue. After rewarming, a fluid-filled blister may appear a day or so later. If all layers of the skin and tissue below the skin freeze, there is severe (deep) frostbite. A person loses all sensation. After rewarming, large blisters form one to two days later and eventually turn black as tissue dies.

Hypothermia A general lowering of the body temperature results in a variety of symptoms. As the core temperature becomes lower than a normal temperature of about 37.5 °C, shivering appears initially. Numbness, lack of coordination, disorientation and confusion. amnesia, and impairment of judgment occur as core temperatures become lower. When temperatures reach 26–30 °C, unconsciousness, cardiac arrhythmia, muscular rigidity, ventricular fibrillation, respiratory arrest, and death are likely to occur. However, people have survived when the body temperature has reached lower values.

Total immersion in cold water quickly leads to hypothermia. Cold water carries heat away from the body 25 times faster than air at the same temperature. The rate of cooling depends on the amount of insulation worn over the body, such as a diving suit. At first, there are shock effects. Then local cooling of muscles can limit their dexterity and ability to function effectively. Eventually, the core temperature drops and unconsciousness occurs. Along the way, many who become immersed in cold water die of drowning. Survival time in cold water depends largely on the water temperature.

Indices of Cold Stress

There are few indices of cold stress. Earlier in this chapter, there was a discussion about the effect of wind speed on the rate of convective cooling. In cold environments, heat loss by convection is the most significant means of cooling. The effect of wind action on cooling has resulted in an indicator of cold stress called wind chill.

Wind Chill

Initial Wind Chill This index originally resulted from measurements of the rate of cooling of a container of water. Antarctic explorers measured the cooling power of wind at some temperature in comparison to the equivalent cooling power of still air at another temperature. The resulting equation derived from the study underestimated the time to freezing and overestimated the chilling effect of the wind.

Revised Wind Chill Temperature Index In 2001, the U.S. National Weather Service issued a new wind chill index. The study, conducted jointly by the U.S. and Canada, considered heat loss from exposed skin using human subjects. The new empirical equation for computing wind chill is

$$\text{Wind Chill} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16}) \quad (18\text{-}14)$$

where

T = air temperature, °F
V = air speed, mph

Most cold weather reports now include wind chill derived from this study. Table 18-11 is the Wind Chill Chart[6] derived from this study. The chart includes times for the onset of frostbite.

Controls

Controls for preventing injury from cold environments include changes to the environment, adjustments in activities, and providing protective clothing. Some divide preventive actions into engineering controls and administrative controls. Engineering controls modify the workplace to eliminate or reduce hazards. Administrative controls provide training, procedures, work planning, communication among workers and groups, protective clothing, and other methods to reduce dangers. OSHA[7] and NIOSH[8] have published recommendations on preventing cold stress.

Modify the Environment For some environments, it may be feasible to warm the air temperature or provide radiant heater. In some situations, reductions in wind speed may be possible by providing windscreens or work enclosures. In some cases, even for indoor workplaces, it is not possible to change conditions. For example, work in cold storage facilities requires temperatures that protect food and other goods.

Adjust Activities The easiest way to protect someone from the cold is to minimize the duration of exposure. Some work schedules require periodic breaks to warm up. If workers wear heavy clothing that increases the work load for tasks, rest periods may be appropriate. In some situations, it may be possible to modify the work itself to reduce work exposure. Rotating workers between cold and warm tasks may retain efficiency while reducing danger from cold conditions.

Provide Protective Clothing Adequate amounts of clothing can provide the insulation necessary to retain body heat (discussed in Section 18-2). The outer layer of clothing should provide a windscreen, but also allow moisture to escape. It is good practice to avoid sweating resulting from too much insulation or condensation of sweat in

TABLE 18-11 Wind Chill Chart[a]

Wind Speed (mph)	Air Temperature (°F)																	
	Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
	5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
	10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
	15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
	20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
	25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
	30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
	35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
	40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
	45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
	50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
	55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
	60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times ■ 30 minutes ■ 10 minutes ■ 5 minutes

[a]http://www.nws.noaa.gov/om/winter/windchill.shtml

clothing. Inner fabrics should absorb moisture so the skin can stay dry. Attention should be given to protection of body extremities including hands, head/face, and feet. Since the hands have a relative large surface area and a large portion of the blood flow through the body goes to the head, both can have high rates of heat loss. In some cases heated clothing may be appropriate. Some clothing has battery power for heated wires built into the clothing.

When workers contact or handle solids and liquids at sub-freezing temperatures, there is a need for protective clothing. The type of clothing and the potential temperatures and hazards encountered should influence the selection of protective clothing. The goal is to prevent freezing of local tissue or allowing moist skin to freeze to objects that are at sub-freezing temperatures.

Where there is a potential for cold water immersion, there should be emergency rafts or other protective equipment. In some situations, workers may need insulated wet suits to complete their work if immersion is possible. There should be an emergency plan for any immersion work.

EXERCISES

1. Estimate how long a person can be exposed to the following conditions before burns will result: Thermal radiation of 150 kcal/m^2/min on the skin.
2. Compute the heat stress index for the following conditions and determine if any precautions are warranted:
   - **(a)** M = 350 kcal/hr, V = 14 km/hr, T_a = 31 °C, $T_w = T_a$, relative humidity at the skin = 100%, relative humidity of the air = 80%.
   - **(b)** M = 200 kcal/hr, V = 5 km/hr, T_a = 21 °C, $T_w = T_a$, relative humidity at the skin = 70%, relative humidity of the air = 40%.
3. Compute the WBGT index for the following and recommend appropriate controls:
   - **(a)** WB = 23 °C, GT = 35 °C, DB = 31 °C, continuous heavy workload, solar load.
   - **(b)** WB = 15 °C, GT = 40 °C, continuous light workload, no solar load.
4. Compute the time weighted average WBGT if a worker doing continuous light work is subjected to the following conditions as a sequence during the 8-hour workday:
   - **(a)** Condition 1: WBGT = 35 °C, duration = 100 min.
   - **(b)** Condition 2: WBGT = 24 °C, duration = 20 min.
   - **(c)** Condition 3: WBGT = 30 °C, duration = 60 min.
   - **(d)** Condition 4: WBGT = 40 °C, duration = 40 min.
5. What is the heat index for each of the following conditions?
   - **(a)** air temperature = 90, relative humidity = 55%

(b) air temperature = 98, relative humidity = 65%

6. What is the revised wind chill for the following conditions?

(a) wind speed = 25 mph, $T_a = 30\,°F$

(b) wind speed = 10 mph, $T_a = -10\,°F$

7. An employee must work in the cold. Determine the insulation required and estimate the insulation that must be provided by the clothing assembly for each set of conditions.

(a) hard work, $T_a = -15\,°C$, calm air

(b) moderate workload, $T_a = -25\,°C$, V = 6 km/hr

8. For the conditions in Exercise 7, estimate the adjustment in insulation required if the employee had the following height and weight:

(a) height = 152 cm, weight = 39 kg

(b) height = 191 cm, weight = 115 kg

REVIEW QUESTIONS

1. Describe the fundamentals of heat exchange between the human body and the environment for:

(a) convection

(b) conduction

(c) radiation

(d) evaporation

2. Identify the physical parameters involved in heat transfer from the human body.

3. What mechanisms can the body use for increasing heat loss? Discuss the limitations of each.

4. Discuss the advantages and disadvantages of clothing in terms of the impacts on thermal balance.

5. What effect does air motion have on heat exchange? How effective is air as an insulator?

6. Under what conditions will turning on a fan add to the heat of metabolism?

7. What is mean radiant temperature?

8. What injuries and illnesses can result from exposure to heat? Describe their symptoms.

9. What instrumentation would you use to determine the following?:

(a) heat stress index

(b) WBGT index

(c) heat index

10. Describe the classifications schemes for burns and typical characteristics for each class.

11. What controls can eliminate or reduce hazards from heat?

12. What maximum deep body temperature should not be exceeded when someone works in hot environments?

13. What injuries and illnesses can result from exposure to cold? Describe their symptoms.

14. What is wind chill?

15. What is the wind chill for each of the following conditions?

(a) air temperature = 25, wind speed = 40 mph

(b) air temperature = −20, wind speed = 20 mph

16. What controls will eliminate or minimize hazards from cold?

17. Define:

(a) hyperthermia

(b) hypothermia

18. What are the symptoms of the following disorders?

(a) trenchfoot

(b) chilblains

(c) cold urticaria

(d) frostbite

NOTES

1 ASHRAE, Standard 55-2013, *Thermal Environmental Conditions for Human Occupancy*, ASHRAE, 3916 Ranchero Dr., Ann Arbor, MI 48108.

2 www.osha.gov/dts/osta/otm/otm_toc.html

3 www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html

4 www.nws.noaa.gov/os/heat/index.shtml

5 C. P. Artz, J. A. Moncrief, and B. A. Pruitt, *Burns*, W.B. Saunders, Philadelphia, PA, 1979.

6 www.nws.noaa.gov/om/winter/windchill.shtml

7 www.osha.gov/SLTC/emergencypreparedness/guides/cold.html

8 www.cdc.gov/niosh/topics/coldstress/

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CHAPTER 19

PRESSURE

19-1 INTRODUCTION

We live in an environment in which the air above us in the atmosphere creates pressure around us. We experience changes in pressure when we fly in airplanes or climb mountains. Some people experience changes in pressure when they go scuba diving or work in tunnels or caissons.

The human body can function within a particular range of pressures. The human body also has limits for the tolerable rate of change.

In explosions there are rapid changes in pressure that can injure people and destroy buildings and other property. There are many products and processes involving elevated pressures where sudden and/or uncontrolled releases can cause injury and damage. Recall from Chapter 17 that some explosions also involve heat in addition to pressure concerns.

19-2 LOW PRESSURE ENVIRONMENTS

Physics

Low pressure environments are those that have a pressure less than sea level. At sea level standard atmospheric pressure is 760 mm Hg or about 14.7 lb/in^2. The air around us contains oxygen, nitrogen, and small amounts of other gases. Our environment contains about 21% oxygen. Nitrogen makes up most of the remaining portion of air.

As we go up in altitude from sea level, the pressure around us decreases. Table 19-1 shows the pressure at various altitudes. However, the gas mixture stays the same.

Because people need oxygen to function, the main concern involves the partial pressure of oxygen. Dalton's law of partial pressure states that the partial pressure P of any gas in a mixture, is equal to the total pressure P_{tot} times the percent of the gas in the mixture:

$$P_x = P_{tot} \times \%\text{gas}_X \qquad (19\text{-}1)$$

For example, at sea level, the partial pressure of oxygen P_{O_2} is

$$P_{O_2} = 760 \times 21\% = 160 \text{ mm Hg}$$

At altitudes above sea level, the total pressure is lower than that at sea level. The partial pressure of oxygen is also lower. Table 19-1 lists the partial pressure of oxygen at various altitudes.

Physiology

The partial pressure of oxygen affects the ability of the blood to transport oxygen throughout the body. The red cells in the blood perform the transport function. They contain hemoglobin, which forms a loose bond with oxygen. When someone inhales air into the lungs, the red cells pick up oxygen from the lungs and release it to cells in the body as the blood circulates. During circulation, the hemoglobin also picks up carbon dioxide from the cells. Carbon dioxide is a waste product of cellular metabolism. The red cells return to the lungs, release carbon dioxide and bond with a new supply of oxygen. The lungs exhale carbon dioxide.

The percent of the red cells actively bonding with and transporting oxygen is normally about 97% at sea level. The level of red cell participation is the oxygen saturation level. With increasing altitude and reduced partial pressure of oxygen, there is a reduction in the portion of red cells effectively transporting oxygen. This relationship is the oxygen dissociation curve shown in Figure 19-1.

To a small extent, the body is able to improve oxygen transport at increased altitude by increasing breathing rate and heart rate. These forms of compensation have limitations. The body can also produce higher concentrations of red cells in the blood. However, this change takes nearly a month for full adjustment. Again, this compensating mechanism has limits. People who live at high altitudes have a higher density of red cells in the blood than those who live at sea level. Athletes who must perform at high altitude will often train in such an environment for some time to allow the red cell adjustment to occur.

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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TABLE 19-1 Pressures at Altitude and Underwater[a]

Altitude or Depth Below Sea Level (ft)	Total Pressure (mm Hg)	Total Pressure (lb/in.^{2})	Partial Pressure of Oxygen for Standard Gas Mixture in Air (mm Hg)
45.000	111	2.15	23.3
40,000	144	2.79	30.2
30,000	223	4.3	46.7
20,000	349	6.8	73.1
15,000	424	8.2	88.8
10,000	523	10.1	110
5,000	632	12.2	132
Sea level	760	14.7	159
100 underwater	3040	58.8	637
200 underwater	5320	103	1115
300 underwater	8360	162	1751

[a]Table data assume fresh water and 33 ft of depth is 1 atm.

Hazards

Hypoxia Hypoxia is a lack of metabolic oxygen reaching cells. A complete lack of oxygen at the cell level is anoxia. A reduction in oxygen transport affects cell metabolism. One can express the oxygen deficiency in altitude, saturation of red cells, or partial pressure. The effects are a result of the degree of hypoxia.

One of the first effects exhibited by hypoxia is loss of night vision. There are two kinds of receptor cells in the retina of the eye. One type, cones, senses color. The other type, rods, senses light, black and white vision. Rods are most sensitive at low light levels. As one goes up in altitude, there is a reduction in the ability of rods to see in low light levels. This effect begins to appear about 6000 ft. As one progresses to higher altitudes, other effects include impaired memory, loss of judgment and coordination, drowsiness, euphoria, syncope (unconsciousness), and death.

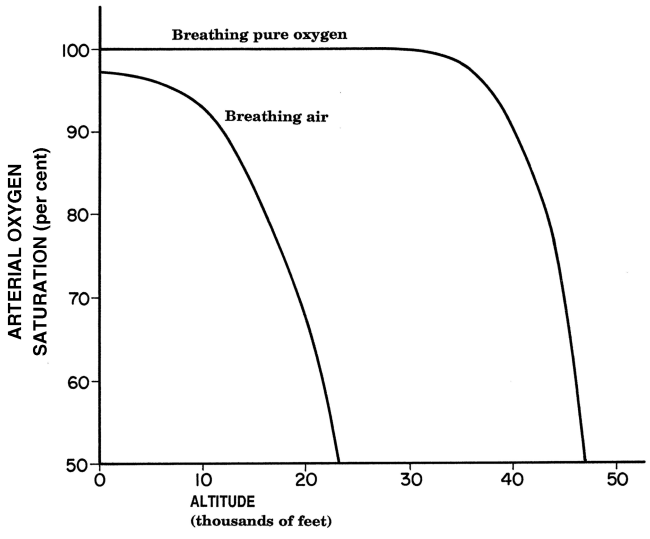


Figure 19-1. The effects of oxygen deficiency caused by low pressure atmospheres are delayed by increasing the oxygen content of a breathing gas mixture.

Pain in Tissues As one goes up in altitude, the middle ear vents through the Eustachian tube into the throat to equalize the pressure on both sides of the ear drum. Altitude reduces pressure outside the ear drum until ears "pop" through a sudden pressure release from the middle ear. This adjustment occurs quite naturally without effort. Swallowing can help to release middle ear pressure.

When one moves rapidly from altitude to sea level, the surrounding pressure is higher outside the ear drum. It is more difficult to equalize the pressure because the opening of the Eustachian tube in the throat may seal shut. The increase in atmospheric pressure can create pain.

With a descent in altitude, pressure can build in other body cavities and produce pain. An example is pain in sinus cavities blocked by mucus.

Oxygen Limits There are limits to the range of partial pressures of oxygen. There are both lower and upper limits for oxygen in breathing air.

If the partial pressure becomes low, the oxygen level in the blood diminishes as seen in Figure 19-1. Then hypoxia become a risk. The lower limit is the equivalent of 16–17% oxygen in breathing air, whether measured in breathing air content or partial pressure of oxygen.

If the partial pressure of oxygen rises too much above that at sea level, oxygen toxicity can occur. Oxygen toxicity usually occurs when oxygen in the breathing air is equivalent to 60% at sea level pressure. Again, the limit can be oxygen as a portion of the breathing air or the equivalent partial pressure. An early sign of oxygen toxicity is a cough. Other symptoms occur with extended breathing of high concentrations of oxygen.

Fire Hazard Recall from a discussion of fire behavior in Chapter 16 that enriched oxygen environments increase fire hazards. Combustion is more rapid in high oxygen environments. High oxygen environments must consider this hazard.

Controls

The primary objective is to maintain the partial pressure of oxygen near that at sea level. For reduced pressure environments, one can accomplish this in two ways: increase the total pressure or increase the portion of oxygen in the breathing air.

Commercial jet aircraft fly at 25,000–40,000 ft. At these altitudes, adjustments in breathing air are essential.

CASE 19-1

January 27, 1967, Cape Kennedy, FL. The crew of the first Apollo spacecraft was conducting a launch site test of all space vehicle systems and procedures in preparation for an actual launch a month later. Gus Grissom, Ed White, and Roger Chaffee were inside the command module working to resolve a microphone problem during a hold in the countdown at T-10. Suddenly the crew reported a fire and emergency inside the command module.

Support personnel located on the tower began rescue efforts. There were three hatches for the command module, making quick access difficult. One was to jettison after launch. Flames filled the command module. A rupture occurred in the module and flames, gases and smoke flowed into the support space, called the White Room. Thick smoke in the White Room hampered attempts to open the hatches.

The astronauts lost consciousness within 15 to 20 seconds following their report of the fire. They soon died.

An extensive investigation revealed several factors that caused the intense fire. Among the findings were (a) many combustibles were close to possible ignition sources and (b) the atmosphere was 16.7 psi with 100% oxygen.

Later findings identified numerous deficiencies in design. One was "no design features for fire protection."[a,b,c]

[a] http://history.nasa.gov/SP-4029/Apollo_01a_Summary.htm
[b] http://history.nasa.gov/Apollo204/find.html
[c] http://history.nasa.gov/Apollo204/content.html

In most commercial aircraft the total pressure inside is above that outside the aircraft and there is an emergency oxygen system in the event that a plane loses cabin pressure.

Manned spacecraft balance the demands for a suitable breathing atmosphere against the weight of a space capsule's structure. The difference between the needed interior environment and the lack of pressure in space determines the design strength and weight of the capsule. A cabin pressure of about 260 mm Hg with 60% oxygen achieves a desired partial pressure similar to sea level. The 60% oxygen level prevents oxygen toxicity. Higher total pressures require stronger and heavier structural elements for spacecraft.

Should a fire occur in an elevated oxygen environment, there is a need to improve fire prevention and protection beyond normal methods.

19-3 NEGATIVE PRESSURE INJURIES

When systems operate with pressure below atmospheric pressure, injuries can result. When operating below atmospheric pressure, there is a vacuum or negative pressure. There are vacuum systems for air and there are some that involve water.

Negative Air Pressure

Hazards A common air system at negative pressure is a household vacuum. There are also industrial grade vacuums. The effectiveness of a vacuum device depends on the amount of suction created and the volume of air moved. Equipment with strong suction operates at a pressure significantly below the surrounding atmospheric pressure. Equipment with weak suction has less negative pressure. The amount of negative pressure produced defines the potential danger of a system. Commercial vacuum cleaners typically produce 2.8 to 4.25 psi (2000–3000 mm of water in a column) negative pressure.

The potential for injury also depends on the area over which the negative pressure applies. The standard hose sizes of commercial equipment typically do not produce injury if an end completely covers the skin.

When a negative pressure applies to a large area, it may cause damage. In some of the methods used to deliver babies, physicians use vacuum extraction equipment to help the birth process. While effective with proper use, medical literature reports possible injuries because of the negative pressure and other forces involved in delivery.

Any powered vacuum equipment may present other hazards based on energy source, moving elements and other factors.

Controls The best control is proper use of vacuum equipment. Avoid applying a vacuum to the skin or body. Medical equipment requires proper training and use.

Negative Pressure Fluids

Hazards A negative pressure acting over some area of the body can create enough force to cause injury. A common example involves use of swimming and spa equipment and contact with fluid flowing into a drain or return port. The Consumer Products Safety Commission has reported numerous cases of children and adults coming into contact with an operational pool drain port. In some cases intestines were

CASE 19-2

19-2a October 25, 1999, Aberdeen, South Dakota. A private Learjet 35 plane carrying Payne Stewart and five others crashed after traveling 1,500 miles with no pilot in control. Payne Stewart was a highly-recognized professional golfer because of his unique style of dress during play.

The flight originated in Florida and was headed for Texas. Apparently, the plane lost internal pressurization. That resulted in the pilot and passengers becoming unconscious and dying and the plane flying on its own until it ran out of fuel. Fighter pilots who tried to intercept the plane reported the windshield had frosted over and non-responsive occupants. Crash debris left little opportunity for analysis of systems.[a]

[a]www.cnn.com/US/9911/23/stewart.crash.03/

19-2b August 14, 2005, Athens, Greece. A Boeing 737 commercial jet operated by Helios Airways departed Larnaca, Cyprus, in the Mediterranean Sea for Athens, Greece. While passing through 10,000 feet on its climb to its flight altitude, the cabin altitude alarm sounded. The pilot and copilot tried to resolve the problem when a similar alarm sounded for lack of cooling air. Pilots programmed the plane for its path to a cruising altitude and final destination and continued beyond 28,900 feet. Most likely, the flight crew did not recognize the lack of oxygen condition and did not use their oxygen masks. Eventually, they probably became unconscious. The plane finally crashed, killing all 121 occupants.

Investigations revealed that the plane had undergone maintenance the night before. The maintenance crew had completed pressurization system checks, but failed to return the Pressurization Mode Selector switch to the "Auto" mode. The maintenance crew had left it in "Manual" mode, used for testing. The flight crew always flew in "Auto" mode and did not detect the failure of the maintenance crew.[b]

[b]http://aviation-safety.net/database/record.php?id=20050814-0

sucked from victims when they sat on a drain.[1] In some cases, hair or limbs become caught in the fluid flow. These cases have the name drain entrapment. In Japan, a 7-year-old child died when sucked into an unprotected intake pipe of a high-volume, water park pump.

Controls The main control preventing contact with the negative pressure water flow is a cover over the drain port that distributes the intake of water through numerous small holes. An additional protection includes automatic shutoff controls when there is a measurable change in suction. These devices are called Safety Vacuum Release Systems (SVRS). Many of these features became pool requirements through the Virginia Graeme Baker Pool and Spa Safety Act of 2008 and associated regulations of the Consumer Products Safety Commission.[2]

19-4 HIGH PRESSURE ENVIRONMENTS

Physics

Pressures greater than that at sea level occur in underwater diving and in certain kinds of construction work, such as caisson construction. Caissons are watertight structures for constructing foundations, such as bridge piers. In tunneling and caisson work, water may seep into the underground work area, so the work area is sometimes sealed and pressurized to minimize the water seepage that can interfere with work. Workers enter and leave the pressurized area through air locks.

Hyperbaric chambers in medical facilities for performing certain procedures operate under elevated atmospheric pressure. They are another example of high pressure environments. Some hyperbaric chambers have solid enclosures and some are simply plastic bubbles. The thicker the walls of the enclosure, the greater the pressure it can contain. Medical hyperbaric chambers have uses in elevated oxygen therapy for burns, gangrene, air embolisms, and other diseases and conditions.

Dalton's law of partial pressure applies to high pressure environments as well as to those below atmospheric pressure. Total pressure under water increases 1 atm for every 32–33 ft of depth. The rate of increase depends on the density of water. Salt water is slightly denser than fresh water.

Assume a worker in a pressurized tunneling project that is 33 ft below the surface works at a total pressure of about 2 atm. Note that the surface pressure is 1 atm and pressure due to depth adds to it. The tunnel example assumes that the pressure at 33 ft below the surface is the same as 33 ft below a water surface. The example assumes that water

leaching from the soil is behaving the same as that depth under water.

Another important phenomenon for high pressure environments involves Henry's Law. This law says that gases will dissolve in fluids that are under pressure. Dissolved gases become a problem when there is a reduction in the pressure. The gas escapes, typically forming small bubbles. We observe this when we open carbonated soft drinks that are under pressure. Eventually, there are fewer bubbles as the fluid reaches a new, reduced pressure level.

Hazards

There are limits to oxygen partial pressures in high pressure environments. If someone pumps surface air to a diver, the portion of oxygen in the air needs to be reduced if the diver is more than 65 ft (3 atm) below the surface. At 3 atm the partial pressure reaches the upper limit set at 60% at sea level. At greater depths, it is rather difficult to control oxygen content to maintain the 60% equivalence at sea level pressure. Control limits become very tight. Enriched oxygen mixtures (partial pressures for oxygen above that at sea level) also increase dangers from fire.

Another problem for high pressure environments involves inert gases used in breathing mixtures. At high pressures, nitrogen creates narcotic effects. Examples are euphoria, drowsiness, and muscular weakness. Nitrogen narcosis is the name for these narcotic effects.

In deep diving, breathable gas mixtures usually replace nitrogen with helium, another inert gas. Helium does not produce narcotic effects until much higher pressures. However, helium also has problems. Speech sounds occur at much higher frequencies in a helium atmosphere. Most people have observed this phenomenon when someone inhales helium from a decorative balloon and then speaks in a funny voice. Also, helium at high pressures exhibits an increase in convective heat loss in comparison to nitrogen.

Contaminant gases in breathing mixtures may add other dangers. That is why there is special equipment for supplying breathing gas to divers. Regular compressors introduce contaminants that may create breathing hazards.

As pressure increases, gas going into solution in the body and the blood according to Henry's Law is not a problem. Dangers occur when someone returns from high pressure to lower or normal environmental pressures. The gas dissolved into body fluids begins to escape. This family of decompression disorders has various names: decompression sickness, dysbarism, the bends, and caisson's disease. Bubbles or embolisms may form in tissues or in the blood. Bubble formation in tissue occurs more often in body joints and creates severe pain. If large enough, bubbles in the bloodstream can interrupt the blood flow in the heart, lungs, or brain, and cause serious emergency conditions.

Controls

Breathing gases supplied to people in high pressure environments need control for proper oxygen partial pressures. Depending on depth, breathable gases also need the proper inert gas. In addition, contaminated gases and particles from compressor equipment and compressor lubricants must be removed from breathing mixtures. The good solution is to provide clean, proper breathing gas at the desired pressure.

Carbon monoxide in a breathing gas can be particularly dangerous. Carbon monoxide bonds easily with hemoglobin and forms a stronger bond than normal oxygen. Because carbon monoxide does not dissociate from hemoglobin very well, it prevents red cells from providing adequate oxygen transport to cells in the body.

When a diver works in a high pressure zone, it is necessary to substitute some other inert gas to prevent nitrogen narcosis. It is also necessary to consider any hazards associated with alternate inert gases.

To prevent decompression sickness, one can either limit the time of high pressure exposure or control the rate of decompression. Diving tables give information about allowable exposure time at various depths or pressures and the procedures and durations for decompression. Decompression may involve more than one stage. Diving experience provides the basis for diving tables. The authoritative source for diving tables is the U.S. Navy.[3] Most other diving tables are derivatives of the Navy tables. OSHA establishes standards for safety in commercial diving.[4]

There are other controls that are important for work in high pressure areas and for diving. Divers must qualify medically and have regular medical examinations. Diving procedures require careful planning. Participants must follow the plans during pre-dive, dive, and post-dive phases. Diving equipment must have regular testing and examination. There must be a diving plan that includes preparations for emergencies and implementation during an emergency. All those participating in a diving operations must know the emergency procedures and complete regular practice of the procedures.

19-5 PRESSURIZED CONTAINERS

There are many kinds of pressurized containers in processes and consumer products. They range from aerosol cans to inflated tires, water heaters, tanks, or compressed gas cylinders. Industry also uses many kinds of pressurized vessels. An example is vehicle air bags. In explosions, even buildings and pipes can be pressurized containers. When pressurized to test for leaks and other faults, pipes, pipelines and some process equipment become pressurized containers.

CASE 19-3

November 13, 2014, Seattle, WA. An employee of a company that supplies seat-belt airbags for aircraft seats was installing the product on an airplane in production. The airbag deployed unexpectedly, striking the employee in the face. The employee died from the incident.[a,b]

[a]www.reuters.com/article/2014/12/20/us-usa-boeing-airbags-idUSKBN0JY02Y20141220
[b]http://seattletimes.com/html/businesstechnology/2025196281_boeingairbagxml.html

Hazards

A container is no stronger than its weakest member, such as a joint, cover, seal, wall, or relief device. Corrosion or physical damage from handling may create a weak point. Containers that have pressurized contents may reach pressures too high for the container or any of its parts. Eventually, a container may leak slowly or rupture suddenly. An example is the explosive release of an air bag during installation or maintenance.

The pressure in a container may exceed its limits from exposures to heat or other conditions. For example, exposure to sun or some other heat source may increase the pressure in a container. A pressurized container may have one or more pressure relief devices. If a relief device fails, the container may leak or burst.

For gases, the Boyle-Charles law helps us predict the pressure change in a pressurized container.

$$P_1V_1/T_1 = P_2V_2/T_2 \qquad (19\text{-}2)$$

where

P = pressure, absolute

V = volume

T = temperature, absolute

and subscripts define the initial and final conditions.

Gauge pressure is the pressure inside a container or pipe represented by the reading on a gauge. Absolute pressure is the pressure in a container plus the atmospheric pressure surrounding it.

Example 19-1 Suppose a gas cylinder contents has 2200 lb/in.^{2} (gauge) at 70°F. After exposure to direct sun, the temperature increases to 180°F. What is the pressure after exposure?

Because the volume is constant, the final pressure is

$$P_2 = P_1T_2/T_1 = (2200 + 15)(180 + 460)/(70 + 460)$$
$$= 2675 \text{ lb/in.}^2 \text{ (absolute)} = 2660 \text{ lb/in.}^2 \text{ (gauge)}$$

A leak in an unrestrained, pressurized container may create enough force from the released gas to put the container in motion. A broken valve fitting on a pressurized gas cylinder can send the container in motion like a missile. Because of the mass and velocity attained, the momentum can send the cylinder through a wall. Similar events can occur in overheated and overpressured water heaters.

Leaking material may have dangers inherent to its temperature or because of toxic or reactive properties. Contact with hot water or high pressure steam will cause burns. A material may inflict injury if it is a caustic or an acid. Inhalation of toxic materials or contact with them may cause harm, depending on the material.

Compressed air in tires, air lines, and equipment may pose fire hazards due to the presence of enriched oxygen. This is particularly true if fuel and sources of heat or sparks are also present.

A sudden release of gas under pressure may produce a pressure wave capable of knocking someone down or causing other damage. Chapter 17 discussed explosions. The pressure wave may cause materials in its path to strike someone and cause injury. The flying materials may damage other equipment or property.

Certain kinds of truck tires or large tires on off-highway equipment pose a danger from sudden release of inflating air. Some truck tires use multi-piece rims. The parts need to be properly fastened before the tire are inflated. Cages are used to house such tires and rims during inflation to protect workers. A sudden failure of a split rim can cause parts to fly and cause serious injury.

Controls

Application of Haddon's energy theory (Chapter 9) helps identify controls for pressure release hazards. Remember, a pressurized container has stored energy. Haddon's energy theory helps one think through the options for controlling potential hazards of pressure. Here are some approaches to consider.

Limit Pressure If there is a need for pressure in an application, the amount of pressure should be as low as possible and not have pressure above design limits. There are

various devices that prevent overpressures. There will be a discussion of them shortly.

Prevent Pressure Buildup Avoid pressure buildup in containers. For example, do not expose pressurized containers to direct sun or other sources of heat. Boyle-Charles Law will add pressure to a container that becomes heated.

Substitute Less Hazardous Materials Aircraft tires are inflated with nitrogen to prevent fire that might otherwise occur. If air has inflated aircraft tires, heat from skids during landing could cause the tires to catch fire.

Control Pressure Release If pressure is released from a container, control the location and direction of the release. That can prevent injuries to those nearby. Consider the temperature of a container's contents. Release of hot contents may burn someone. Hot water and steam are common hot materials. Directing the release to a safe location will prevent potential burns. The contents may have toxic properties. A relief path through a pipe to a location not likely to be in a breathing zone will prevent inhalation. The path may also lead to a capture container. In some cases, barriers may separate people from heat, dangerous properties, pressure waves, or flying objects. For example, tire cages and other tire-restraining equipment can prevent some injuries from accidents while inflating truck and other large tires. An enclosed control station for a process can be a form of barrier.

Remove Pressure When Not Needed Avoid unnecessary pressures and reduce pressure for certain activities. During setup, maintenance, cleaning, and other operations, deenergize and depressurize equipment before starting the work. Observe lockout and tagout procedures when servicing pressurized equipment.

Train Employees in Pressure Hazards Train workers about the dangers of pressurized equipment and containers. They must learn how to recognize these hazardous conditions and how to protect themselves from associated dangers.

Overpressure Devices

There are several overpressure devices, each with particular applications. Some devices are suitable for gas and some for steam, others for liquids. Some work for combinations of gases, vapors, or liquids. Some require more maintenance and testing than others to ensure they operate correctly and reliably. Some are subject to corrosion, scale buildup, and other problems that could render them inoperative or make them operate poorly. Valves are suitable for clean materials, because they must reseat after relieving pressure. Valves minimize loss of material. Rupture discs are better for relieving large volumes and corrosive, dirty, and viscous fluids. Pressure relief devices and components like pipes that direct releases to a safe location must have a size sufficient for the flow and type of materials released.

The American Society of Mechanical Engineers (ASME) has a standard for pressurized piping and containers. A well-established standard is the Boiler and Pressure Vessel Code.[5] ASME also has standards for piping, flanges, fittings, and other elements under pressure. The standards give specifications for installation and certification testing of overpressure devices.

Safety Valves A safety valve actuates when the upstream pressure exceeds some predetermined value. The valve rapidly opens fully or pops open to relieve the pressure. There are safety valves for gas, steam, and vapor.

Relief Valves When the upstream pressure exceeds some predetermined level, a relief valve opens in proportion to the amount of overpressure. It closes when the pressure has returned to an acceptable level. Relief valves are primarily for liquids.

Safety Relief Valves These valves become activated by upstream pressures that exceed some value. The valves serve as safety valves or relief valves. They are used in liquid or in gas, steam, or vapor applications.

Frangible Discs/Rupture Discs Frangible discs or rupture discs are relatively flat metal pieces. Their design allows each disc to burst at a particular pressure. Their normal mounting is between two flanges along a vent pipe. They range in size from less than ½ in. diameter to about 4 ft. Rupture pressures range from a few ounces to very high pressures. Other design considerations include the number of pressure cycles, selecting material because of potential corrosion, temperatures encountered, and other factors. Rupture discs usually release large quantities of process material when they fail and perform their function, whereas valves release small quantities. Failure of a disc may produce significant downtime for replacement of the disc, replacement of lost materials, and restart of a process. For activation, some rupture discs require a quantity of explosive material connected to a sensing device and a detonator control. Rupture discs applications include liquids, gases, steam, or vapor.

Fusible Plugs A fusible plug is a plug made of a metal that will melt at a selected temperature and relieve pressure in a container. Fusible plug applications include boilers, compressed gas cylinders, and other pressure vessels. They allow overpressure to vent when a container becomes heated from fire or other sources. A plug may consist entirely of the alloy

that will melt or have a high temperature metal core surrounded by the low temperature alloy.

Discharge Lines or channels approaching or leaving a pressure relief device must be the right size to provide adequate flow of materials. Discharged materials must flow to some location where there is no danger to people from high temperatures, high flow rates, or pressure waves. High volume discharges should lead to adequately sized holding areas or containers.

Freeze Plugs Another type of pressure relief device is a freeze plug. Water and many water-based liquids expand near the freezing point. A freeze plug will allow the liquid to expand and drain, thereby reducing the likelihood of damage. A freeze plug may control the location of failure if its placement is at a location that can freeze. It may be possible to reduce the risk of damage even further by using antifreeze solutions together with freeze plugs.

Temperature Limit Devices According to the Boyle-Charles Law, gas pressure will increase and decreases in closed containers as content temperatures rise and fall. Processes and containers where exceeding pressure limits create dangers may incorporate temperature limit sensors and special controls to minimize the dangers from temperature changes.

Vacuum Failures Pressure reduction in a container can damage it. For example, a tank can collapse while being drained if there is nothing to replace the removed contents. Even if there is venting, the vent line must provide adequate flow rates to prevent formation of a vacuum.

19-6 HIGH PRESSURE FLUIDS

Gases and liquids under pressure are very common. There are hydraulic systems and compressed air systems for many purposes. Examples are paint sprayers, grease guns, hydraulic and pneumatic tools, spray applicators for agricultural chemicals, water hoses used in fire fighting and landscaping, hydraulic cylinders and lines for mechanical equipment, and fuel injection devices in engines. Some mining methods use fine streams of water or water mixed with fine abrasives to cut rock and perform mining functions. Pressure testing of pipelines and process equipment can create temporarily pressurized systems. Gases and liquids under pressure and the lines and hoses used to distribute them have dangers.

Hazards

Pressurized gases and fluids can cause injury. Major hazards are air and gas injuries, injection injuries, and whipping of lines.

Air and Gas Injuries Getting pressurized gas or air into the internal organs can cause injury or rupture tissues. For example, some people use compressed air to clean parts. If someone places the nozzle of a compressed air line in the mouth with air flowing, the air can inflate and injure internal organs and tissues.

Injection Injuries Injection injuries occur when a fine stream of gas or fluid enters the body. Fine streams of air, gas, or liquid can penetrate the skin. Medical inoculations with injection guns apply this principle.

A fine stream may look safe because it is so small. It may seem harmless because of the familiarity with water or some other common liquids without pressure. However, fine streams can cause serious injection injuries. Medical literature reports injection injuries resulting from fluids with fine streams at 650 to more than 7000 lb/in.^{2} Equipment operating at much lower pressures can create such pressures.

High pressure streams of fluids can easily make incisions in skin and other tissue. Fluid injected through even a tiny hole in the skin can migrate quickly throughout several layers of tissue. Removal is extremely difficult because of the distribution among the tissue. If the fluid is toxic or contaminated with infectious microorganisms, amputation is often the only solution. Delays in onset of treatment can result in radical treatments for injection injuries. Injection injuries typically involve the fingers and hands. Such injuries also occur to arms, face and other parts of the body.

A gas injected under the skin may create embolisms in the bloodstream. If the embolisms migrate to the lungs or heart, they can interrupt the functions of these organs and cause death.

CASE 19-4

Vehicle maintenance garage. A mechanic was working on the fuel injection system of a diesel engine. He was trying to determine if an injector was operating properly. He placed his finger on the opening in the injector that released the pressurized fuel. The injector sent a small release of fuel into the mechanic's finger. The fuel passed into many parts of the finger. Treatment resulted in amputation of part of the finger, since there was no way adequately to remove the fluid from all of the affected tissues.

CASE 19-5

South Dakota. The operator of a backhoe received severe injection injuries to his hand. A hydraulic line started to leak. A small, high-pressure stream of hydraulic fluid struck the operator's hand, penetrated the skin and filled a significant part of his hand with fluid.

There was a box supporting four levers for controlling the bucket. Hoses from the hydraulic pump entered and left the sides of the box. The hoses were fabric-reinforced hoses. The hoses were about 4 inches from the operator's hand when positioned on the levers. One hose created a very fine stream of hydraulic fluid when it started to fail. The stream sprayed directly to the normal hand position.

Alternate designs could have prevented the injury. For example, a guard extending from the supporting box over the hoses could have prevented a hydraulic fluid leak from spraying onto an operator's hand. Another design option was using solid lines in the area near the control box.

Whipping Lines Fluid moving through a nozzle creates reactive forces at the nozzle. If the forces are large enough, they can cause the nozzle and hose to move back and forth or whip. If the hose or nozzle strikes someone, it can cause serious injury. If the hose or nozzle strikes an object, it can damage it.

Controls

There are several possible controls for reducing dangers of high pressure fluids.

Reducing Pressure One control for the hazards of compressed air lines is to reduce the pressure to a low level. OSHA requires compressed air for cleaning purposes to be 30 lb/in.^{2} or lower. Pressure-reducing nozzles drop the line pressure to 30 lb/in.^{2} or less. Setting pressure regulators on general use air lines to 30 lb/in.^{2} or less minimizes the danger to users.

Distance Distance is one possible method for reducing the danger of pressurized fluid lines. Controls for reducing the hazards of compressed gas and fluid lines include distance, guarding, and the use of solid lines. Increasing the distance of hydraulic lines from people or body parts reduces the force of released fluid by the time it contacts a person. Leaking hydraulic hoses have caused injection injuries. For example, a line leading to a control box may be within a few inches of an operator's hands. Keeping lines away from hands or fingers can reduce the chance of injury.

Solid Lines Solid lines do not leak as readily as hoses, which develop leaks from vibration, repeated pressure changes, bending, and aging. Where lines must come close to people, solid lines and tight, well-maintained fittings reduce the chances of a leak.

Guards Hoses or lines that come near people should have the extra protection of guarding. A shield of metal or other

CASE 19-6

Southern Illinois coal mine. A 100-ton haul truck moved mined coal from the open pit to the surface. The operator sat in an elevated cab. There was a vertical ladder that led from the ground to a landing near the cab. The landing was about 15 feet above the ground.

The haul truck had hydraulically powered steering and other controls. The large hydraulic system, including the reservoir for the system, contained more than 50 gallons of hydraulic fluid.

The exhaust from the engine flowed upward through a channel that provided heat to the haul bed in cold weather. The intention was to keep wet coal from freezing and icing up.

A hydraulic hose connector ruptured and sprayed hydraulic fluid onto the exhaust channel. The fluid caught fire. The hydraulic fluid leak continued to feed the fire. The pump for the hydraulic system continued to push fluid through the leak. The fire quickly surrounded much of the cab and continued to grow with the release of more hydraulic fluid. The operator stopped the haul truck, quickly exited the cab and jumped to the ground from the landing. He sustained broken ankles and crawled away from the haul truck.

One option available during purchase of the haul truck was a built-in fire suppression system intended to extinguish any fire created by the large and complex hydraulic system. There was no fire suppression system on this haul truck.

materials that a fluid stream cannot cut easily gives this protection.

Extinguishers If high pressure fluids are flammable, there is a potential for a leak causing a fire. Where fire hazards exist, fire suppression equipment must be available.

Effective Planning and Communications When there is pressure testing of pipelines and process equipment, workers should be at a safe distance from any potential rupture points along the line. Instruments for reading pressures should not require workers to remain close to pressurized lines. There should be written plans for testing procedures. If there is a compressor and operators for pressuring a pipeline or container for testing, and they are some distance from other workers involved in testing, radio communication between crews is essential. Without communication equipment, one crew may not be aware of what the other is doing or the pressure condition of the line or equipment. A distant crew may not know what pressure is in a line or container and make an error in their testing tasks. DOT regulations[6] and other references, such as the American Petroleum Institute,[7] give detailed procedures for pressure testing of pipelines transporting hazardous liquids.

Training People who work around compressed air lines, hydraulic systems, and other pressurized fluid and gas equipment should learn about the hazards. They should learn not to place fingers or hands against a fluid stream and they should learn not to place the stream near anyone else. Protective gloves and clothing may help reduce injection injuries.

EXERCISES

1. A full gas cylinder contains nitrogen gas at 70°F and the maximum allowed pressure [2640 lb/in.^{2} (gauge)]. If it were left in the sun and the contents reached a temperature of 210°F, what is the resulting pressure in the cylinder?
2. A caisson worker must work under water at a depth of 60 ft digging a tunnel under a river. Assuming a 33 ft column of water is equivalent to 1 atm, determine the following:
   (a) the pressure for the worker in millimeters of mercury
   (b) the partial pressure of oxygen if air is pumped from the surface (assume standard sea level conditions) to the worker
   (c) the percent oxygen if supplied air is from the surface
3. In a diving operation, assume the upper limit for oxygen at sea level is 40% (where oxygen toxicity starts to appear) and the lower limit is 16% (hypoxia occurs), what is the allowable range for oxygen in the breathing gas mixture (percent of total) when a diver is submerged to 600 ft below sea level?

REVIEW QUESTIONS

1. What is Dalton's law of partial pressure?
2. What effects do low atmospheric pressure and low oxygen partial pressure have on the body?
3. What are the hazards of high altitude?
4. What controls can eliminate or reduce the dangers of high altitude?
5. What is Henry's Law?
6. What is the significance of Henry's Law for people who work in high pressure atmospheres?
7. What are the hazards of high pressure atmospheres?
8. What controls can reduce the dangers of these hazards?
9. What are alternate terms for dysbarism?
10. Identify three hazards associated with high pressure containers.
11. What controls can eliminate or reduce these hazards?
12. What is a hyperbaric chamber?
13. Explain the operating principle for the following overpressure devices:
    (a) safety valve
    (b) relief valve
    (c) safety relief valve
    (d) frangible disc
    (e) fusible plug
    (f) freeze plug
14. When there is a release from overpressure, identify a hazard and control for the release.
15. By what principle of physics are temperature and pressure interrelated?
16. Identify a hazard associated with high pressure
    (a) hydraulic lines
    (b) air lines
17. What is a suitable control for each hazard in question 16?

NOTES

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2 www.poolsafely.gov/pool-spa-safety-act/read/

3 www.dtic.mil/get-tr-doc/pdf?Location=U2&doc=GetTRDoc.pdf&AD=ADA540531

4 www.osha.gov/OshDoc/Directive_pdf/CPL_02-00-151.pdf; 29 CFR 1910, Subpart T

5 www.asme.org/shop/standards/new-releases/boiler-pressure-vessel-code-2013

6 http://phmsa.dot.gov/regulations

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CHAPTER 20

VISUAL ENVIRONMENT

This chapter addresses the visual environment, which includes lighting, color, and signage. Many aspects of the visual environment contribute to accidents while other characteristics help prevent them. Engineers need to understand the visual environment and how it relates to accidents and their consequences.

20-1 ILLUMINATION

Lighting or lack of lighting can contribute to accidents. People need to see to perform tasks and where they are going. Some aspects of lighting create distractions or interfere with tasks. One study suggests that about one-fourth of all accidents involve poor lighting. Another study found that falls are much more frequent in the evening and at night. That suggests a relationship between lighting conditions and accidents.

Illumination and Lighting

The human eye detects light in wavelengths within the range of 380–750 nm in the electromagnetic spectrum (see Figure 21-1). Ultraviolet light lies below and infrared above the visual range.

Figure 20-1 illustrates a light source and what happens to light distributed from it. One must know and understand the units of measure involved in illumination and lighting. The intensity of a light source has units of Candela or candlepower. Often light sources assume a "point" source, although that is not always the case. The output of a light source, such as a lamp, has units of lumens (lm), which originally was defined as the light from a standard candle falling on a 1 ft^2 area 1 ft from the candle.

Light leaving a source goes in many directions. It may not scatter uniformly in all directions. As light travels farther from its source, its energy diminishes. Like other radiant energy sources considered point sources, light intensity decreases with the square of the distance from the source. The light at one unit of distance from a source becomes ¼ the amount at two units from the source. Flux is the light traveling through some unit of area. Luminous flux has units of lumens (lm).

Light from a source arrives at a surface. Illumination is light falling on a surface. Illumination has units of footcandles (fc) or lux (lx). If 1 lm arrives at a 1 ft^2 surface, the illumination is 1 fc. If 1 lm arrives at a 1 m^2 surface, the illumination is 1 lx (1 fc = 10.764 lx; 1 lx = 0.0929 fc).

The light arriving at a surface is absorbed, transmitted, or reflected. The reflectance of a surface is the reflected portion of arriving light. Reflectance is a property of the surface and units are percent of arriving light.

Luminance is the light emitted or reflected from a surface per unit area. Luminance has units of foot lamberts.

There are daylight and artificial light sources. Most artificial light sources are electric lighting devices. Typically, a lighting fixture has a lamp and a luminaire. A lamp is the light source. Luminaires help distribute light in some desired pattern.

There are several types of artificial light sources. Major types are incandescent, fluorescent, and high intensity discharge (mercury and sodium vapor, and halogen). A more recent lighting type involves light emitting diodes (LEDs). Each type produces a different spectrum of wavelengths. Each type has different energy efficiencies. Suppliers can no longer sell some types of incandescent bulbs, an energy-efficiency strategy.

There is general lighting and supplementary lighting. General lighting provides lighting to a large area. It may be direct, which allows light to move from the source directly to surfaces or locations. It may be indirect, which provides light by reflecting it from surfaces such as walls or ceilings.

Task lighting is a common form of supplementary lighting. Located near a particular task, task lighting supplements general lighting to provide the amount and quality of light required. Task lighting quality may involved special colors or wavelengths, special angles to create or prevent reflection or simply to elevate the amount of light to assure accurate and precise work.

Emergency lighting is another class of lighting important for safety. Typically, emergency lighting is backup lighting that provides light when normal light sources fail

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 20-1

May 5, 1973, Miami, FL. All three engines in an Eastern Airlines L-1011 jumbo jet failed because O-ring seals were missing. The failure nearly caused the pilot to ditch the plane and its 172 passengers in the Atlantic Ocean. During the investigation of this incident, mechanics for the airline testified that it was too dark in the service area to see if the very small seals were in place.[a]

[a]www.rvs.uni-bielefeld.de/publications/Incidents/DOCS/ComAndRep/Eastern/Ntsb8404.html

or have interruptions. A common purpose for emergency lighting is to illuminate exit routes. Fire, life safety, and building codes specify emergency lighting. Emergency lighting has its own alternate power supply. Common backup power supplies are batteries. In some cases, power comes from emergency generators that provide backup power for emergency lighting and critical equipment and activities.

There are other lighting types. A common special lighting type is lasers. Lasers create coherent light at specific wavelengths. Coherent light does not spread out very much, in contrast to most lighting sources. Laser light travels a long distance in a very narrow path. People use low energy lasers for presentation pointers. Some carpentry equipment includes lasers that help position objects or make them level. Some survey equipment uses lasers to measure vertical and horizontal positions.

Hazards

The major hazards associated with lighting involve illumination levels, changes in illumination levels, qualitative aspects of lighting, and flicker of some light sources. Some hazards also involve energy level.

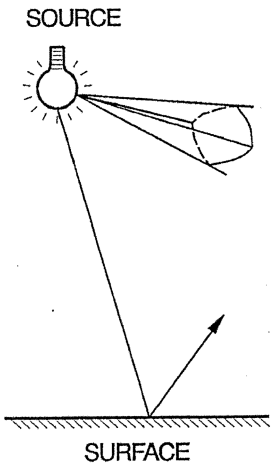
Illumination Levels. If there is too little light, one cannot see well. Insufficient light leads to errors and sometimes accidents. An error may involve placing a hand in a dangerous location or machine, not seeing a step and falling or failing to detect a problem or to see a faulty part. An error may result from not seeing a situation that is dangerous and reacting quickly enough.

Extremely bright light sources can injure the receptor cells in the eyes. For example, a brief look directly at the sun can damage eyes. Similarly, looking at light generated in arc welding can cause eye injuries very quickly.

A bright light in the visual field may interfere with the ability to see or detect an object. The result may be visual errors that produce accidents.

Even when bright lights do not cause injury, injuries can increase after images that obscure portions of the visual field until the receptor cells have had a chance to recover. The afterimage from a flash of a camera or similar bright light is a common experience. The afterimage may lead to vision errors and to accidents.

Changes in Illumination Level Changes in illumination level interfere with the ability of the eyes to adjust quickly enough to permit seeing without error. Examples of changing light levels are the transition from bright outdoor light to dark interiors or from a bright area of a building to a dark one. Another example is looking at a brightly lit task, then turning the eye to focus on a location that is darker. There is some loss in visual acuity and perception until the eyes adjust to the new light level.



LOCATION	TERM	UNITS
Source	Luminous Intensity Luminous Flux	candela lumens candlepower
Arriving at Surface	Illumination	footcandle lux
Reflection from Surface	Reflectance (Luminance/ Illumination)	percent
Light Reflected	Luminance	footlambert candelas/sq m

Figure 20-1. Light distribution and illumination terminology.

CASE 20-2

1988, Champaign, IL. A patron entered a restaurant from the bright sunlight for a noon lunch appointment. The restaurant lighting was dim to create an aesthetic effect. There was a two-step change between the small lobby and the seating area. The patron fell down the steps that were only a few feet from the entrance. The patron claimed he was unable to see the steps.

CASE 20-3

Continuing and increasing laser incidents. The Federal Aviation Administration continues to compile reports of people on the ground pointing lasers at aircraft. Most cases occur near airports. In some cases, the pilot becomes blinded temporarily when a laser beam points directly in his eyes.

Visually disabling a pilot during critical take- off or landing procedures places many people at risk. There is an increasing number of laws at federal and state levels that create fines and imprisonment for offenders who get caught.[a,b]

[a] www.faa.gov/about/initiatives/lasers/laws/

[b] www.faa.gov/about/initiatives/lasers/hazards/

There are two ways the eyes adjust to changing light levels. In one form of adjustment, the iris increases and decreases in diameter to adjust the size of the pupil. This occurs quite quickly to changes in illumination. The pupil size also changes in response to startle and interest. Pupils enlarge when a person is surprised or interested in someone or something.

The eyes also adjust photochemically to changes in light level. The range of photochemical changes may be as large as 100,000 times or more. The concentration of rhodopsin in receptor cells of the retina changes cell sensitivity to light.

Light adaptation is the adjustment with increases in light level. Increased light arriving at the retina reduces light sensitivity by reducing the concentration of rhodopsin. Eyes achieve full light adaptation in about 3 min. Dark adaptation is the adjustment with decreases in light level. When light levels decrease, the retina must adjust to the dark. The concentration of rhodopsin must increase in the receptor cells. Full changes in rhodopsin concentration for dark adaptation may take from 30 min. to several hours.

Qualitative Aspects of Lighting Glare and luminous contrast are qualitative aspects of lighting. Glare is the presence of a bright light in the visual field. Glare can lead to errors in perception and detection that result in accidents. Glare may produce afterimages or delay visibility due to adaptation.

Direct glare occurs when there is a significant light source in the visual field. An example of direct glare is the headlights of an oncoming car at night. Another is bright light coming through a window that makes it difficult to see the details of a person or object positioned in front of the window.

Reflected glare occurs when a bright light is reflected from a surface. An example of reflected glare is the reflection of a light on a glossy page as the reflected light obscures the print.

Luminous contrast refers to the changing light levels in an environment. For example, one may look at work on a desk that has a certain illumination. The eyes may shift to a different object or location with a much darker or lighter level of illumination. When there is too much difference between the two surfaces, the eyes have difficulty adapting, which may lead to visual errors.

An example is a well-lit task for detailed work and then turning to a distant person or object that is much darker. If there is frequent movement between the two locations, a worker may have difficulty seeing objects precisely with each new location until the eyes adapt to the new light level.

Flicker and Strobe Effects Some light sources are not constant. Flicker involves light sources turning on and off rapidly. The gas in a fluorescent tube actually turns on and off 120 times per second under 60 Hz electrical power. Most people do not notice the on–off effect. For some people flickering light sources are distracting or disturbing and some people are sensitive to fluorescent light flicker.

Flicker-fusion frequency is the number of frames per second required to create smooth motion in movies and video. Early movies used 16 frames per second with noticeable flicker. The flicker fusion frequency is on the order of 15–18 frames per second for most people. Movie theaters

today show film at 24 frames per second and show each frame twice, creating 48 frames per second. Analog broadcast television uses 60 frames per second. HD television is higher.

When an object oscillates or rotates and a bright light flashes on and off at the same frequency as the motion, the object appears to stand still. One can measure the speed of rotating machine parts with a strobe light that has an adjustable flash frequency. A person who does not realize that the light source is flashing on and off may perceive that an object is not in motion. A potential error is sticking a hand or object into a machine's moving part that appears not to be moving.

Energy Levels Each light source consumes energy at some rate. We commonly rate light bulbs in watts. For most light sources, energy level is at fairly low levels. However, lamps may get hot even at low energy levels. Direct contact may cause burns.

A lens that focuses the sun on a small area increases the energy level at an object's surface. Equipment that involves lenses or glass that focuses light can create fires.

The energy level for a laser determines the potential for injury or damage to eye cells, skin, and objects, or materials. Low energy lasers, such as those in presentation pointers, do not cause injury to tissues. Military lasers may operate at levels that can produce tissue damage when beams are direct or reflected. Some medical lasers have energy levels to perform incisions, tissue fusion, or other effects. Some military and manufacturing lasers have high energy levels that burn or melt objects and metal. The higher the energy level, the greater the risk of injury or damage.

Other Lighting Effects There are other effects of light that can be distracting or lead to errors in vision and visual perception. Some workplaces use sodium vapor lights to reduce energy costs. Sodium vapor lights produce light that is primarily in the yellow region. The light makes normal colors appear different. As a result, some may not perceive color-coded information correctly. These lamps have a glass cover that prevents ultraviolet (UV) light escaping to the lighted area. If the glass cover is cracked, damaged or missing, the UV rays can reach occupants. Extended exposures can cause skin and eye irritation and injury.

Recent studies have determined that a small portion of the population suffers from seasonal affective disorder (SAD). This condition affects people during the winter months in northern climates when there is reduced daylight. Depression may result. It can be severe and severely affect performance. A daily dose of high intensity, full spectrum (nearly matching the spectrum of sunlight) fluorescent light for 2–4 hours eliminates the depression in 90% of the cases.

When there is a bright light source in the visual field, one tends to turn the head and eyes toward it. This phenomenon is called phototropism. The presence of such lights can be distracting and can distract someone's attention from a task.

Shadows may cause errors in perception of an object, but they may also be beneficial. Shadows may make some objects appear different than they really are. Shadows can help in some tasks. For example, someone may drop something and not see it lying on the floor or carpet. Using side lighting, such as with a flashlight or work light, a shadow for the object can be created. The shadow allows one to distinguish the object from the background surface.

Characteristics of People That Affect Lighting Hazards

Individual variations among people add to potential problems associated with lighting and vision. Not all working people have effective vision and not all conditions have effective corrections. This section discusses some common eye problems. All of these variations and conditions may lead to visual errors and accidents.

Eyes have two kinds of receptor cells: rods and cones. Cone cells are receptive to color, while rods are not. However, rods are more sensitive to low light levels.

Night vision involves the differences between the two kinds of receptor cells. Night vision refers to the function of rod cells in low light. Studies indicate that rod cell sensitivity in low light diminishes somewhat with age. Compared to someone who is 20 years old, a 45-year-old person needs four times the light to achieve the same level of perception in low light. By age 60, the light levels needed double compared to age 45.

Many people aged 55 and older have some degree of cataracts. Cataracts are an opaqueness that develops in the lens and its encapsulating tissue. Cataracts may also occur on the cornea. Cataracts filter the light entering the eye. That creates at least three potential vision problems. One is loss of visual acuity because of reduced light reaching the retina. Cataracts also cause light to scatter. If cataracts are severe enough, the scattering can produce multiple images. The secondary images may be partial images or almost the same as the primary images. Cataracts usually reduce color perception. Colors do not appear as bright as they normally would. Cataracts may cause other vision problems. In extreme cases, cataracts cause blindness.

There are many visual disorders that require correction. Some result from aging. The most common disorder is acuity. Some people's lenses cannot focus on objects that are too close or too far away.

Another common disorder is stigmatism. The cornea or lens is not uniform and creates distortion of an image at various locations over the surface. Without correction of individual visual conditions, visual errors are likely to increase.

TABLE 20-1 Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors

Type of Activity	Illumination (lx) Category	Illumination (lx)	Ranges of Illuminances Category (fc)
General lighting throughout space			
Public spaces with dark surroundings	A	20-30-40	2-3-4
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20
Illuminance on task			
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200
Illuminance on task, obtained by a combination of general and local (supplementary lighting)			
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000	200-300-500
Performance of very prolonged and exacting visual work	H	5000-7500-10,000	500-750-1000
Performance of very special visual tasks of extremely low contrast and small size	I	10,000-15.000-20,000	1000-1500-2000

Another visual disorder is macular degeneration, most commonly associated with aging for some people. The receptor cells near the center of the retina deteriorate. The person with this disorder progressively loses vision and has difficulty identifying objects when looking at them.

Controls

Lighting systems and applications are complex. The number of standards organizations adds to the complexity. The International Standards Organization (ISO) offers standards for illumination and the variety of equipment providing illumination. In the U.S., ANSI offers several standards for workplaces[1] covering

- Workplace Specific Lighting Standards
- Emergency Lighting Standards
- Lighting Design Standards
- Lighting Energy Standards
- Outdoor Lighting Standards
- Indoor Lighting Standards
- Lighting Standards

There are illumination standards for highways and other facilities. In addition, several industry groups and government agencies at the federal, state, and local levels specify illumination requirements. For example, the U.S. General Services Administration has illumination standards for many government buildings and facilities.[2] OSHA has minimum illumination levels for construction.[3] Some local fire and life safety codes include illumination standards. An Australian standard[4] provides an example of lighting standards in a country that uses risk-based safety systems. It is important to determine which standards apply in specific locations.

A primary source of information on lighting systems and applications is the Illuminating Engineering Society (IES).[5] It produces the *IES Lighting Handbook*, which contains lighting standards, guidance, and engineering information for a very wide range of lighting applications. IES updates this publication periodically to stay current with lighting equipment and practice.

Illumination Levels Illumination standards determine the amount of light suitable for various tasks. The type of task defines most illumination standards. Some standards include adjustment factors for age, speed, or accuracy and reflectance of the task background. Table 20-1 provides an example of recommended illumination levels for interior lighting. They may not apply to a specific location. Standards that apply locally may have variances for other factors, such as types of lighting sources. Sources of lighting include incandescent, florescent, mercury vapor, sodium vapor, and LED. The purpose here is to develop some familiarity with the structure and content of some illumination recommendations.

Table 20-1, derived from IES, organizes tasks into several groups, each group denoted by a letter of the alphabet. Each group has three illumination levels. Table 20-2 offers weighting factors to consider in selecting one of the three levels. The guidance considers several factors based on the location and its occupants. Multiple weighting factors may apply. Table 20-3 provides information for deciding which of the three values in Table 20-1 to select.

Example 20-1 Assume that a visual task involves small sized objects and medium contrast. It is also known that some of the people who will perform the task are over 55 years old. Speed for the task is critical. The reflectance of the task background is 50%. What is the preferred illumination level?

From Table 20-1, the task falls within Category E. There are three illumination levels possible. To decide which

TABLE 20-2 Weighting Factors to be Considered in Selecting Specific Illuminance within Ranges of Values of Each Category

	Weighting Factor		
For illuminance categories A through C			
Room and occupant characteristics	−1	0	+1
Occupant ages	Under 40	40–55	Over 55
Room surface reflectances[a]	>70%	30–70%	<30%
For illuminance categories D through I			
Weighting Factor			
Task and worker characteristics	−1	0	+1
Worker ages	Under 40	40–55	Over 55
Speed and/or accuracy[b]	Not important	Important	Critical
Reflectance of task background[c]	>70%	10–70%	<30%

Notes: [a]Average weighted surface reflectances, including wall, floor and ceiling reflectances, if they encompass a large portion of the task area or visual surround.
[b]In determining whether speed and/or accuracy is not important, important or critical, the following questions need to be answered: What are the time limitations? How important is it to perform the task rapidly? Will errors produce an unsafe condition or product? Will errors reduce productivity and be costly?
[c]The task background is that portion of the task upon which the meaningful visual display is exhibited.

of the three is preferred, determine the adjustment factor. From Table 20-2, age has a +1 factor, speed a +1 factor, and reflectance a value of zero. The total is +2. According to Table 20-3 for Category E, when a weighing factor is +2 or +3, the high value from Table 20-1 is used. Therefore, the preferred illumination level is 1000 Lx.

Fire, exit, and life safety codes typically define minimum light levels for exits and exit routes. In some cases the minimum level is very low. That level may not be sufficient for transition zones where one experiences a sudden change in illumination. This is particularly true if the transition involves dark adaptation. The life safety and exit codes also have standards for emergency lighting. Other standards may offer minimum illumination levels for safety in general. Table 20-4 offers some recommendations for minimum illumination levels.

TABLE 20-3 Decision Data for Selecting Illumination Values within Categories

Categories	Sum of Weighting Factors	Value to Use
A to C	−2 or −1	Low
	0	Medium
	+1 or +2	High
D to I	−3 or −2	Low
	−1, 0 or +1	Medium
	+2 or +3	High

TABLE 20-4 Minimum Illuminance Levels for Safety[a]

Hazards requiring visual detection Normal[b] activity level	Slight Low	High High	Low	High
Illuminance levels				
Lux	5.4	11	22	54
Footcandles	0.5	1	2	5

Notes: [a]Minimum illuminance for safety of people. These are absolute minimums at any time and at any location on any plane where safety is related to seeing conditions. Refer to *IES Handbook* for recommendations on particular types of facilities and areas.
[b]Special conditions may require different illuminance levels. In some cases higher levels may be required as, for example, where security is a factor. In some other cases greatly reduced levels, including total darkness, may be necessary, specifically in situations involving manufacturing, handling, use or processing of light-sensitive materials (such as photographic products). In these situations alternate methods of ensuring safe operations must be relied upon.

Maintenance Note that in all illumination designs, one may need to start with illumination levels higher than desired because the luminaires and lamps normally get dirty and reduce actual illumination levels with time. Cleaning will restore original lighting levels.

Quality of Lighting The quality of lighting may affect error rates and cause accidents. For many applications control of illumination levels alone is not sufficient. Designs must control illumination quality as well. For example, users of computer screens are more likely to experience eye strain and other visual problems when there are combinations of poor reflectance, brightness ratio, and contrast ratio.

Reduce Glare and Reflectance One should analyze workstations to avoid direct or reflected glare. This is particularly true where tasks are critical or continue for extended periods. For example, a surface of a machine that has a dangerous action may be or become polished. A light source reflected at the polished surface obscures the dangerous operation. The condition could lead to erroneously placing hands in the danger zone at the wrong time.

Screens on computer monitors can also create work-related cases. Reflections of light sources on the screen can cause eye strain and visual errors. The reflected glare may result from reflections of nearby windows or overhead lighting. A user may adjust the head position that leads to fatigued neck and shoulder muscles or related effects. Some call this family of cumulative disorders VDT (visual display terminal) syndrome or computer vision syndrome. Recent monitor designs reduce such problems through non-glare monitor surfaces.

Table 20-5 offers recommendations for reflectance of surfaces in industrial facilities.

Brightness Ratio One should also analyze work stations for brightness ratio or luminance ratio. Luminance

CASE 20-4

Central Illinois. An elderly couple arrived at their physician's office for a medical appointment. After parking in the doctor's parking lot, they proceeded to enter the office building through a side door, rather than walking to the front of the building. It was a bright, sunny day.

The side entrance had a landing inside the entry door. From the landing, there was a single step and a second door leading to the waiting area. The door swung outward over the landing. Along the side of the landing there was also an open stairs leading to the basement of the office building. The light fixture for the landing was not on.

As the husband began to open the interior door, he had to step back a little to allow the door to pass him so he could then step up into the interior area. His wife was close behind him. She stepped aside and fell down the basement steps.

A contributing factor in the accident was the major change in light level and very little chance for dark adaptation.

ratio compares the difference in lighting level between the task and the surround. One is brighter than the other. A preventive strategy is keeping the brightness ratio low. This reduces the degree of light adaptation required in a visual task as eyes focus on the task, then the surround and back to the task. There are often practical limitations that may not permit achievement of this goal. IES and ANSI offer minimum luminance and luminance ratios in various environments. Table 20-6 offers some recommendations on maximum luminance rations.

Example 20-2 An industrial task is to be illuminated to a level of 100 lx.

(a) If a recommended illuminance ratio between a task and an adjacent surround is 3 : 1, what is the highest illumination level for the surround?

(b) If the recommended ratio for a remote surface is 10 : 1, what illumination level should the remote surface have?

The adjacent area should not exceed $100 \times 1/3 = 33.3$ lx. The remote surface should have $100 \times 1/10 = 10$ lx.

Contrast Ratio Contrast ratio refers to the intensity ratio between the darkest and lightest areas of a display. For a newspaper, the ratio between print and paper is 50 or more. Reading gray print on white or black paper is more difficult. Eye strain results if the ratio is too low. To prevent eye strain, computer screens should have the contrast properly adjusted.

TABLE 20-5 Recommended Reflectance Values[a]

Reflectance Surface	(%)
Ceiling	80–90
Walls	40–60
Desk and bench tops, machines and equipment	25–45
Floors	not less than 20

Note: [a]From ANSI/IES RP7-1979, *Practices for Industrial Lighting*.

Texture The texture of a surface can also lead to visual errors and accidents. For example, a textured pattern in a carpet that continues from a floor to stairs can create an illusion. Someone looking at the floor may not detect where the stairs begins, may mis-step and fall. It is better to use non-texture finishes on stairs and certain walking surfaces. A change in finish may help someone see that the change reflects a change in elevation or a potential tripping hazard.

Strobe Effects If oscillating or rotating equipment operates at frequencies similar to lighting with flicker, a good solution is to prevent potential injuries through guarding. This is particularly true when there is gas-vapor lighting that might produce strobe effects. Guarding the moving elements will stop effects from failure to recognize whether the equipment is moving.

20-2 COLOR

Color and Safety

Color is useful in safety for marking hazards and coding information. For example, color can be used to mark the edges of steps and other changes in walking surfaces. It can code classes of information, including safety information and

TABLE 20-6 Recommended Maximum Luminance Ratios[a]

Ratio, Environmental Class[b] Surfaces	A	B	C
Between tasks and adjacent darker surroundings	3:1	3:1	5:1
Between tasks and adjacent lighter surroundings	1:3	1:3	1:5
Between tasks and more remote darker surfaces	10:1	20:1	–
Between tasks and more remote lighter surfaces	1:10	–	–

Notes: [a]From ANSI/IES RP7-1979, *Practices for Industrial Lighting*.
[b]A = interior areas where reflectance of surfaces can be controlled. B = areas where reflectances in immediate work area can be controlled, but control of remote surround is limited. C = areas (indoor and outdoor) where it is impractical or difficult to control reflectances.

TABLE 20-7 Standard Color Codes for Marking Hazards[a]

Color	Use
Red	Fire equipment, danger, emergency stops
Yellow	Caution, hazards
Green	First aid, safety equipment
Black/white	Traffic marking, housekeeping
Orange	Dangerous parts of machines or equipment
Blue	Informational signs
Reddish purple	Radiation hazards

Note: [a]Excerpt from ANSI Z53.1, *Safety Color Code for Marking Physical Hazards*.

signs. Table 20-7 offers one set of color codes for hazards. MIL-STD 1472G[6] limits color coding when required to the following colors: red, green, orange-yellow, white and blue. Each color has federal color/paint standards.

One limitation for color coding is that a small portion of the population is color blind. Color blindness occurs primarily among males. About 6% of adult males have a marked reduction in color sensitivity and less than 1% of adult males are totally color blind. Color blindness can lead to visual errors. For example, color-blind electricians have attached the green ground wire in equipment to a hot lead and energized equipment incorrectly. A color-blind driver depends on the vertical position coding of red and green traffic signal lights to correctly interpret the signals. In the U.S. color coding of lights, including those on display panels, red means stop and green means go. Changes in that convention will lead to errors.

Another limitation of color coding is that one must remember the meaning of the colors. However, if color coding occurs consistently over time, the general meaning of the colors becomes well known in a culture. We call such well-known conventions population stereotypes. Chapter 33 discusses population stereotypes further.

Color Standards

Color poses complexities similar to lighting and illumination. Not everyone sees and remembers colors exactly the same. Color characteristics include hue, saturation, and other characteristics. Hue is what is the color is, such as red, green, blue, and yellow. There are actually millions of hues, which makes color complex. Saturation is the purity of a color. High saturation colors look rich and full. Low saturation colors look dull and grayish.

To use colors in safety to convey meaning requires standards. One of the first issues is being able to match color in paint, fabric, video screens, and other places. One widely used system that allows one to specify or match a color is the Pantone Matching System (PMS).[7] The company provides color swatch books to assist in color matching and specification through a numbering scheme. Many designers use this system to specify colors.

There are several standards that define color specification for safety information. For example, OSHA color codes define types of hazards.[8] The Federal Highway Administration publishes color standards for marking information and hazards on highways and for clothing in its *Manual on Uniform Traffic Control Devices (MUTCD)*.[9] There are standards for safety-related color coding for electrical wiring and equipment and for piping systems. The standards help prevent errors and accidents in equipment and operations.

20-3 SIGNS

Signs and Safety

Signs take many forms. They may be large to provide safety information for a large area or they may be in the form of tags for lockout and tagout procedures. They mark hazards at particular locations on machines and equipment and in buildings and provide warnings on products. They need to

CASE 20-5

March 28, 1979, Three Mile Island, PA. One of the nuclear power plants on this island in the Susquehanna River near Harrisburg, PA, experienced a loss-of-coolant accident. The event involved many complex issues. One class of problems involved the design of displays and controls in the plant control room.

During the first minute of the event, nearly 300 audio and visual signals and displays went off. Operators had difficulty recognizing the pattern underway and what decisions to give priority to.

One example was some status display lights not following the convention learned in the U.S. that red means stop or danger and green means go or no danger. Operators misinterpreted the display and made a decision error.[a,b]

[a]B. Sheridan, "Human Error in Nuclear Power Plants," *Technology Review*, February: 23–33, 1980.
[b]*Report of the President's Commission on the Accident at Three Mile Island*, Washington, DC, October 1979. Available at: www.threemileisland.org/downloads/188.pdf

incorporate standard safety color codes where applicable. For many use environments, signs should be multilingual.

Many signs related to safety include symbols that are independent of language. Not everyone understands symbols. Symbols are more effective if coupled with text information.

Sign Standards

There are many standards for marking hazards and communicating safety information through signs, tags, and related notices. Several U.S. government agencies have standards for safety-related signs for workplaces, products, vehicles, and other applications. Other countries publish similar standards. Some standards come from international standards organizations.

A frequently used standard for safety signs, tags, and other information is ANSI Z535. It has six parts:

- ANSI Z535-1, *Safety Colors*
- ANSI Z535-2, *Environmental Facility and Safety Signs*
- ANSI Z535-3, *Criteria for Safety Symbols*
- ANSI Z535-4, *Product Safety Signs and Labels*
- ANSI Z535-5, *Safety Tags and Barricade Tapes*
- ANSI Z535-6, *Product Safety Information in Product Manuals, Instructions, and Other Collateral Materials*

OSHA has adopted much of this standard for workplaces.

Other government and private organizations publish standards for some safety signs. For example, the American Society of Agricultural Engineers publishes a standard for design and placement of the slow-moving vehicle emblem.

There is a United Nations system for labeling hazardous materials. ISO publishes standards for signs and symbols. Many consensus standards contain specifications for signs. Examples are the National Electric Code and the National Fire Code. Chapter 16 (Figure 16-4) discussed identification signs for hazardous materials storage. Various countries publish safety sign standards. For example, the Australian government publishes standards for product safety that include labeling standards. There is considerable variation in the detailed requirements in each standard.

Signs must meet many characteristics, particularly when used as warnings and instructions. Refer to Chapter 7 for a discussion of warnings and instructions for products. Tables 7-1 and 9-2 provided characteristics of warnings. Chapter 33 discusses characteristics of visual displays that reduce reading errors. Chapter 33 also discusses the size of text that people can read from various distances and the importance of font for readability.

The most recent ANSI Z535 standard adopted by OSHA in 2013 specifies certain format and other features for safety signs worth considering. Refer to Figure 20-2 for one example. This standard divides safety signs and tags into three components: hazard alerting safety messages, symbols, and text messages. The standard also specifies colors.

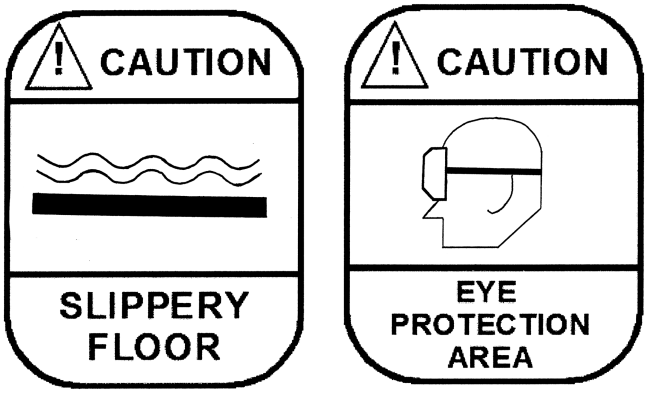


Figure 20-2. Examples of caution signs.

There are five possible safety messages in specific colors to appear across the top of a sign. They are DANGER (red), WARNING (orange), CAUTION (yellow), NOTICE (blue), or SAFETY INFORMATION (green). The first three may also incorporate a safety alert symbol. This is a triangle with an explanation point on a yellow background (see Figure 32-1).

The space below the safety message has two components, each occupying part of that space. One space may contain one or more symbols. Symbols are graphics that help bridge languages and draw attention to the safety message. Symbols should meet global standards.

The other space below the safety message contains a text message for the intended audience. The text messages should have clear and concise information about the hazard and proper action by the reader.

EXERCISES

1. What illumination level is recommended for public areas with dark surroundings, where all age groups will use it, accuracy of information is importan, and reflectance of the task background is 35%?
2. What illumination level is recommended for an industrial task involving very small items for an entire workday, where items are of low contrast? Several workers are over 55 years old and speed is critical. The task background has a reflectance of 65%.
3. An assembly task is to have 40 fc of light. If more remote surfaces are darker than the task, what is the least amount of light you would recommend for the surrounding dark surfaces?

4. You are to design the entrance to a restaurant. The interior decor is to be dimly lit to create an intimate dining mood. The decor is to be in place even at lunch time, when full sunlight may be present outdoors. Part of the dining area is to be sunken relative to the entry level and other parts are to be elevated from it. Determine what lighting levels and lighting placement you would recommend for different areas of the restaurant. Justify your decisions, allowing for visual accommodation of patrons. Some patrons may be over 65 years old, have some form of cataracts or suffer from macular degeneration. What other design features would reduce hazards?

REVIEW QUESTIONS

1. What units of measure are used for the following forms of light?
   - **(a)** light output from a source
   - **(b)** luminous flux
   - **(c)** light arriving at a surface
   - **(d)** light emitted or reflected from a surface
   - **(e)** reflectance of a surface
2. Characterize the following:
   - **(a)** general lighting
   - **(b)** supplemental lighting
   - **(c)** direct lighting
   - **(d)** indirect lighting
3. For each of the following identify at least one hazard and control:
   - **(a)** illumination level
   - **(b)** change in illumination level
   - **(c)** qualitative aspects of lighting
   - **(d)** flicker of a lighting source
4. How long does full light adaptation take?
5. How long does full dark adaptation take?
6. Which receptor cells in the eyes are sensitive to color?
7. Which receptor cells in the eyes are most sensitive to low light?
8. How do cataracts affect vision?
9. How is color used for safety?
10. Name two limitations for using color coding.
11. Name one limitation of text signage.
12. Name one limitation of symbols.

NOTES

1 http://webstore.ansi.org/workplace-lighting/default.aspx?source=blog

2 www.gsa.gov/portal/content/101308

3 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10630

4 www.worksafebc.com/Publications/OHSRegulation/Part4.asp?ReportID=18005

5 www.ies.org/

6 *Department of Defense Design Criteria Standard: Human Engineering*, MIL-STD-1472G, January 2012. Available at: www.public.navy.mil/navsafecen/Documents/acquisition/MILSTD1472F.pdf

7 www.pantone.com/pages/pantone/pantone.aspx?pg=19970

8 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9793

9 http://mutcd.fhwa.dot.gov/

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CHAPTER 21

NON-IONIZING RADIATION

21-1 THE ELECTROMAGNETIC SPECTRUM

Electromagnetic radiation has a spectrum of wavelengths, illustrated in Figure 21-1. Wavelengths range from long (3×10^{8} m) and very low frequency (1 Hz) to short (3×10^{-15} m) and very high frequency (10^{23} Hz). There are several bands in the spectrum. The bands help organize important properties. Key bands include gamma and X-rays. There are also ultraviolet, visible, infrared, microwave, television and radio, induction heating, and power waves.

Many parts of the electromagnetic spectrum are radiant energy sources. Some sources, like the sun and fires, are natural sources of radiant energy. Others, like microwaves, radio transmission, atomic reactors, lamps and lasers, are sources from manufactured items.

Photon energies of electromagnetic radiation are proportional to radiation frequency and inversely proportional to wavelength. Some sources have energy levels high enough to ionize atoms or molecules or break the bond of molecular elements. There must be enough energy, about 10–12 eV or more, to break these bonds. Wavelengths in the lower portion of the spectrum usually fall below this minimum energy level. They are the non-ionizing portion of the spectrum. Those in the high wavelengths are the ionizing portion.

Some properties of electromagnetic waves depend on frequency. For example, some wavelengths are visible. Some can penetrate and heat materials, including human tissue. Some properties apply across the spectrum. For example, energy from a radiation source diminishes with the square of the distance from the source. Compared to one unit from a source, the energy level at two units away will be one fourth.

Energy levels for non-ionizing radiation do not affect molecular structure. However, non-ionizing radiation can change the energy level in biological tissue, often producing heat. Some tissues, like that of the eye, heat more easily than other tissue. A primary reason is the low level of blood circulation, which limits the heat removed from the tissue. Biological tissue absorbs some wavelengths but is transparent to other wavelengths. In addition, some wavelengths penetrate deeper into tissue than others. Figure 21-2 illustrates the general absorption properties of the eye for electromagnetic radiation.

The specific absorption rate (SAR) is the power absorbed by a human body when exposed to a radio frequency field. The most common exposures involve microwaves and ultrasound (through magnetic resonance imaging, MRI). SAR is the power absorbed per mass of tissue with units of W/kg.

With the increased use of radiation in products and equipment, there are laws that control radiation emissions.[1] There are also several government standards in the United States and other countries, and consensus standards that apply to radiation equipment, human exposures, and measurement.

21-2 MICROWAVES

Microwaves have wavelengths from about 1 mm to 10 m and frequencies from about 30 MHz to 300 GHz. Microwaves are used in communications, navigation, medical diathermy, microwave ovens, in drying equipment, and other applications. A variety of devices produce microwaves.

Hazards

Microwaves with wavelengths less than 3 cm become absorbed in the outer skin. Those with 3–10 cm wavelengths penetrate from 1 mm to 1 cm into the skin. Wavelengths of 25–200 cm penetrate to deeper tissue and organs. Human tissue is essentially transparent to microwaves with wavelengths greater than 200 cm.

Most absorbed microwave radiation gets converted to heat. Tissue and potentially body temperatures rise, depending on exposure time and locations exposed. Temperature increases in deeper tissue may cause damage before one senses heating. Absorption by other materials may also produce heating, possibly raising temperatures high enough to become a burn hazard.

Microwave sources need electrical grounding. That helps prevent electric shock and burn hazards for people

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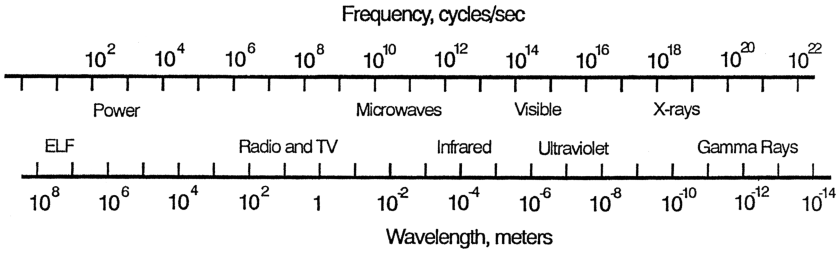


Figure 21-1. Electromagnetic spectrum.

who may come into contact with microwave equipment. Objects, such as fences and vehicles, near microwave power source also need grounding. They may couple to radio frequencies.

Eyes have the greatest danger from microwaves. Microwaves often have a cumulative effect on the lens of the eyes, ultimately producing cataracts. The onset of cataracts depends on frequency, power density, duration of exposure, and intervals between exposures. There is some evidence that microwaves also affect the central nervous system in various ways. They also affect the performance of some types of cardiac pacemakers.

A beneficial use of microwaves on humans is diathermy. Localized application of levels up to 100 mW/cm^2 produces heating and promotes healing in joints and other tissue.[2]

Controls

One control to prevent microwave injury is limiting exposure. One can accomplish this by limiting the intensity of microwaves (the frequency or wavelength of an exposure) or limiting the duration of exposure. Distance from a source and shielding can also control intensity of exposure. Table 21-1 lists the attenuation of various shielding materials.

Before implementing controls, one must determine what potential exposures exist through analysis and/or measurements. Comparing an exposure to exposure standards will help determine if there is a need for controls.

Other controls are signs to warn about radiation hazards or dangers. One can wear specialized protective clothing and eyewear for microwave exposure. Microwave protective clothing incorporates metal fibers that create shielding. Protective glasses and goggles have a woven screen for shielding. Workers should use insulated gloves when handling equipment near microwave sources to reduce shock and burn hazards.

High-powered microwave equipment must be grounded to reduce electrical hazards. Metal objects may build a charge from the electrical field of the microwave equipment. Interlocks on doors protect access to hazardous microwave locations. The interlocks prevent unauthorized access to hazardous microwave locations. The interlocks require frequent inspections and testing to ensure they are working properly. Lockout and tagout procedures are important for servicing of microwave equipment.

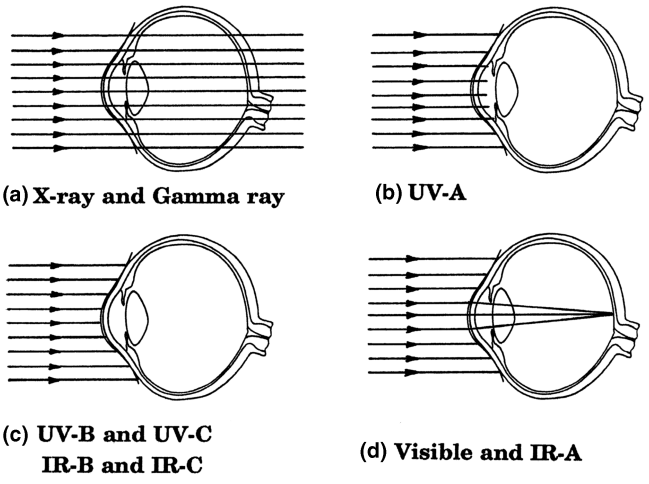


Figure 21-2. General absorption properties of the eye for electromagnetic radiation. (a) X-rays and gamma rays. (b) Ultraviolet A. (c) Ultraviolet Bands B and C and infrared Bands B and C). (d) Visible and Infrared Band A.

Standards

Microwave exposure standards appear in several publications. One source is OSHA standards,[3] which limit power density to 10 mW/cm^2 for exposure periods of 0.1 hr or more. For exposures shorter than 0.1 hr, the energy density limit is 1 mW-hr/cm^2, with limited excursions above 10 mW/cm^2.

The American Conference of Governmental Industrial Hygienists publishes workplace exposure limits based on power density, electric field strength squared, and magnetic field strength squared for particular frequency bandwidths.[4] This standard includes radio and microwave frequencies. Table 21-2 lists the ACGIH Threshold Limit Values (TLVs), which provide guides for evaluation and control of exposure to radio frequency and microwave radiation. Radio frequency radiation exposures should be as low as reasonably possible.

TABLE 21-1 Microwave Shielding Attenuation Factors

Material	Frequency (GHz)			
	1–3	3–5	5–7	7–10
60 × 60 mesh screening	0.01	0.003	0.006	0.01
32 × 32 mesh screening	0.016	0.006	0.006	0.016
16 × 16 window screening	0.016	0.01	0.01	0.006
1/4-in mesh (hardware cloth)	0.016	0.032	0.06	0.1
Window glass	0.63	0.63	0.50	0.45
3/4-in pine sheathing	0.63	0.63	0.63	0.45
8-in concrete block	0.01	0.006	0.006	0.001

The U.S. Federal Communication Commission (FCC) also has exposure limits for microwaves and other radiation frequencies.[5] FCC standards apply to cell phones and transmission equipment. The cell phone limit is 1.6 W/kg.[6]

The Institute of Electrical and Electronic Engineers (IEEE) also has standards for radiation exposure. They appear in an ANSI standard.[7]

The Food and Drug Administration sets standards for microwave ovens.[8] Included in the standard is a limit for the amount of microwaves that can leak from an oven throughout its lifetime. The limit is 5 mW/cm^2 at approximately 2 in. from the oven surface.

The Australian government has established standards for exposures to radiofrequency fields.[9]

Measurement

One can measure microwaves with thermal or electrical detector instruments. Thermal detectors assess temperature rise in a material receiving microwave radiation. Electrical detectors convert microwaves into direct current. Most instruments have factory calibration for particular microwave frequencies and intensities.

21-3 ULTRAVIOLET RADIATION

Ultraviolet radiation important for safety falls in the region between 200 and 400 nm. In this region, photon energy levels range from 4.4 to 3.1 eV. Air, water, and window glass are transparent for wavelengths in the 300–400 nm range and ordinary window glass and skin absorb wavelengths from 200–320 nm. The ozone layer absorbs much of the ultraviolet energy from the sun in the wavelengths below 290 nm. Although ultraviolet wavelengths extend below 200 nm, these wavelengths do not transmit well through air or the air absorbs them fully.

One classification scheme for ultraviolet radiation has three spectral bands:

- UV-A or near ultraviolet includes wavelengths from 315–400 nm.
- UV-B extends from 280–315 nm.
- UV-C extends from 100–280 nm.

Wavelengths from 200–315 nm are of greatest concern in safety and health. This band is the actinic UV region.

The sun is the most notable source of ultraviolet radiation. Some other sources include heliarc welding,

TABLE 21-2 Radio Frequency and Microwave Threshold Limit Values[a,b,c]

Frequency	Power Density, S (W/cm^2)	Electric Field Strength, E (V/m)	Magnetic Field Strength, H (A/m)	Averaging Time E^2, H^2, or S (min)
30 kHz–100 kHz		1842	163	6
100 kHz–1 MHz		1842	16.3/f	6
1 MHz–30 MHz		1842/f	16.3/f	6
30 MHz–100 MHz		61.4	16.3/f	6
100 MHz–300 MHz	10	61.4	0.163	6
300 MHz–3 Ghz	f/30			6
3 Ghz–30 Ghz	100			$33{,}878.2/f^{1.079}$
30 Ghz–300 Ghz	100			$677.62/f^{0.476}$

[a] f = frequency in MHz.

[b] The exposure values in terms of electric and magnetic field strengths are obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). At frequencies above 30 GHz, the power density TLV® is the limit over any contiguous 0.01 m^2 of the body surface.

[c] *2015 Threshold Limit Values and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH. (Note: See publication for additional details. This publication is updated annually and standards may change.)

mercury and xenon discharge lamps, certain lasers, full spectrum fluorescent lamps, tanning lamps, and bacteria-killing lamps.

Hazards

There are several dangers from exposure to UV light. Dangers include burns, skin aging, skin cancer, and photokeratitis.

Burns One hazard of ultraviolet exposure is skin burns or erythema (reddening). With extended exposure, blistering can occur. Skin does not absorb all UV wavelengths in the same way and the erythemal effects vary across the absorbed spectrum. The outermost layer of the skin (the stratum corneum of the epidermis) absorbs the wavelength below 280 nm. Deeper layers of the skin (dermis) absorb wavelengths between 280 and 320 nm. The outer layer (epidermis) absorbs wavelength between 320 and 380 nm.

Exposures to wavelengths at or near 300 nm are most likely to produce erythema. Erythema has a latent period of 2 hrs or more, depending on the degree of UV exposure. Erythema is less likely or reduced with increased natural or conditioned (tanned) levels of pigmentation. Some people expose themselves to UV to get a "tan." Such exposures cause the pigment in the skin (melanin granules) to migrate toward the surface (tanning).

Skin Aging Skin aging (photoaging) is another hazard of extended UV exposure, as is skin cancer. UV exposure causes the destruction of collagen in the skin. This contributes to the loss of skin suppleness and structure that occurs with age.

Skin Cancer Skin cancer occurs more frequently among people who spend considerable time in sunlight. Skin cancer is more prevalent among those who have little skin pigment. People with a history of severe UV burns, particularly if severe burns occur in childhood (young skin), have a higher incidence of skin cancer. People with occupations requiring extensive work in sunlight and those who live in sunny regions have higher rates of skin cancer.

There are three major types of skin cancer. Not all skin cancer results from UV exposure. Basal cell carcinoma is the most common and usually isolated to a small location. Squamous cells compose most of the epidermis. Squamous cell cancer can occur anywhere in the body. However, it occurs most often on skin with significant exposures to UV. Melanoma occurs on skin anywhere and is the most aggressive form of skin cancer, often spreading to other areas of the body.

Photokeratitis Another hazard of UV exposure is keratitis. i.e., inflammation of the cornea of the eye. Photokeratitis is a painful, temporary condition associated with UV exposure. A related condition is conjunctivitis, which involves inflammation of the tissue covering the eye (mainly the white part of the eye). Short, high energy exposures from welding and other sources can produce these injuries.

As noted in Figure 21-2(b), the cornea absorbs UV in the 280–400 nm range and some UV in the 200–280 nm range. The threshold for injury is greatest at or near 280 nm. Initially, one has a sensation of "sand in the eyes." In addition, the eyes may water, vision may become blurred, and the eyelids may swell shut.

Controls

The primary controls for UV exposures are limiting exposure, particularly to most harmful wavelengths, limiting intensity, and using absorbing materials such as clothing and sunscreen. In some cases it may be possible to limit the UV energy at the source.

Limit Exposure Limiting exposures to UV prevents erythema or photokeratitis. The exposure depends both on the duration and intensity of UV irradiation. Limiting extended exposures appears to reduce the likelihood of skin cancer. However, there are other factors involved in skin cancer risks.

Selective Wavelengths All UV wavelengths can produce harm. However, the effects that are most likely to appear differ according to wavelength. Controlling exposure to the most harmful wavelengths can help reduce risks of skin burns and cancer. For example, informed selection of UV lamps, which differ in wavelengths emitted, will lessen risks.

Similarly, protective coating for the skin, such as suntan lotions and creams, may filter certain wavelengths. They have a sun protection factor (SPF) rating, that rates filtering of UV rays in general. The ratings of products range from zero to over 40. Some filtering ingredients are more effective than others, because each ingredient protects for different wavelengths.

Wear Protective Clothing It is quite easy to shield the skin and eyes from UV exposure. Shielding limits the energy level reaching the eyes or skin. Because many materials readily absorb UV radiation, one should select those eliminating or minimizing harmful UV exposures. For example, welders and others must have clothing that covers the skin, including face, arms, and hands. The clothing must protect also against burns from hot particles and materials. Welders need masks or glasses with the proper density of material in the viewing window. See also Chapter 28 on protective clothing.

People who work outdoors or engage in tanning need protection for skin and eyes. Tanning lotions have a sunscreen index and sunglasses have a UV absorption index, both of which indicate degrees of shielding. Protective

eyewear must accompany sunlamp use. Wide-brimmed hats help keep sunlight from the face and neck.

Sun Screen The U.S. Food and Drug Administration (FDA) sets standards[10] for sun screen products, including labeling standards. Broad spectrum sun screen products protect against UVA and UVB radiation. These products prevent sunburn and other kinds of sun-induced skin damage. They include a sun protection factor (SPF) rating of 15 or higher. Sun screen products with only a SPF value between 2 and 14 protect against UVB radiation and sunburn only.

Standards

There are several standards on ultraviolet exposures. The American Medical Association recommends limiting UV exposures (based on a 254 nm threshold) to 0.5 μW/cm^2 for exposures up to 7 hr and 0.1 μW/cm^2 for exposures up to 24 h.[11] The American Conference of Government Industrial Hygienists (ACGIH) maintains exposure standards based on wavelength, exposure time, and irradiance.[12] The Food and Drug Administration regulates sun lamps, ultraviolet lamps,[13] and high-intensity mercury vapor discharge lamps.[14]

The UV Index is an index for planning sun-safety outdoor activities.[15] The UV Index predicts the peak level of solar UV radiation in a day and estimates the risk from overexposure. The index has a simple scale from 0 to 12. Local weather forecasts around the world use this index. There is a computer model with an empirical formula based on stratospheric ozone concentration, cloud amounts, and elevation from the ground that estimates the ground-level strength of solar UV radiation. The UV Index started in Canada and is a standard of the World Health Organization and other organizations. Table 21-3 lists the UV Index values and their interpretations.

Measurement

There are a variety of ultraviolet detection devices. They convert radiation arriving at a sensing device or medium to some form of display. Conversion methods include electrical (photovoltaic cells and phototubes), thermal (thermopile), and chemical (photographic plates). For most devices, selective filters determine what wavelengths arrive at the sensor.

21-4 INFRARED RADIATION

Infrared radiation has wavelengths from 700 nm to 1 mm. Within these wavelengths, there are several smaller bands. IR-A (near infrared) is the spectral region from 701–1400 nm. IR-B includes wavelengths from 1.4–100 nm. The IR-C spectrum is 0.1–1 mm.

Most radiative heat transfer involves the infrared region. Sources of infrared are typically sources of radiant heat. That includes fires and open flames, stoves, electrical heating elements, certain lasers, and many other sources.

Hazards

Near infrared radiation (700–1400 nm) passes through the lens of the eye to the retina or is refracted from other tissues. See Figure 21-2 (c and d). High energy levels can cause a variety of eye disorders. One eye disorder is scotoma which produces a loss of vision. This is damage to the retina at locations which absorb infrared radiation. Other disorders range from simple reddening from low-level exposures to swelling of the eye, hemorrhaging, and lesions. Extended exposures to infrared radiation can cause cataracts. Common examples are glassblower's and bottlemaker's cataracts that result from looking into fire and heat sources. Iron workers who peer into furnaces extensively also have a high incidence of cataracts.

High levels of infrared heat can also ignite materials and create fires. Refer to Chapter 16.

TABLE 21-3 UV Index

Value	Risk	Color	Meaning
0 1 2	Low	Green	Low danger from UV radiation for the average person.
3 4 5	Moderate	Yellow	Moderate risk of harm from unprotected sun exposure.
6 7	High	Orange	High risk of harm from unprotected sun exposure. Protection needed.
8 9 10	Very High	Red	Very high risk of harm from unprotected sun exposure. Take extra precautions. Unprotected skin and eyes will be damaged and can burn easily.
11 12	Extreme	Purple	Extreme risk of harm from unprotected sun exposure. Take all precautions. Unprotected skin and eyes can burn in minutes.

Controls

To limit the danger from infrared radiation, limit the duration of exposure and the intensity of exposure. Because the danger is mainly to the retina of the eye, people should avoid looking into infrared sources. Shielding is an easy way to reduce exposure and exposure intensity. Protective eyewear that absorbs and reduces the amount of infrared reaching the eye prevents potential damage for those who must work around infrared sources. Lenses in glasses, goggles or face shields must have the correct shade and density to reduce harmful levels See also Chapter 28 on personal protective equipment (PPE).

21-5 HIGH INTENSITY VISIBLE LIGHT

Visible light occurs in the region from 380 (violet) through 750 nm (red). It passes through the cornea and lens and reaches the retina. See Figure 21-2(d). There are many sources of visible light including natural light from the sun and artificial light sources. Most objects we see involve reflected light. Chapter 20 discussed lighting and the visual environment. The focus here is on high energy visible light.

Hazards

If energy levels for visible light are too high, they can cause injury to the eyes. Injury may involve the retina and other parts of the eye. Welding, carbon arc lamps, and some lasers are sources of high intensity visible light. Section 21-6 discusses lasers.

Controls

One control is placing a high intensity light source inside an enclosure so light does not reach people. There may be an opening for the light to point precisely where needed. Carbon arc lamps usually have enclosures except for the aperture to direct the light where it is needed. Lasers with dangerous levels of visible light also have enclosures. During maintenance, workers may need to access the enclosure interior. The workers must reduce the energy level and apply lockout and tagout procedures.

Another control is limiting source intensity. Analysis may show that lower light levels are sufficient and reduce any hazard from the light.

Shielding is also a control. For example, portable panels screen welding operations, so bright light produced by welding arcs does not reach people other than welders.

Filtering is a possible control. Welders should wear protective eyewear that has the applicable filter density for the type of operation. See Chapter 28 on personal protective equipment.

21-6 LASERS

The word laser is an acronym for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation. A laser is a source of intense, coherent, and directional optical radiation. Most lasers have an energy source, a resonant cavity, and an active lasing medium. A laser system is an assembly of electrical, mechanical, and optical components that includes a laser.

Lasers and laser systems are becoming quite common in today's high technology society. There are lasers for welding and machining, for medical procedures, for accurate measurement of distance, construction, and alignment of equipment. Lasers have uses in mining and stress analysis of metals. Grocery and retail checkouts devices that read barcodes and other symbologies have holographic devices based on laser technology.

Hazards

Some lasers are dangerous. Others are not. The hazard depends on the intensity, wavelength, duration of exposure, means of exposure, and the part of the body exposed. Some lasers have continuous wave (CW) emissions. Others have pulsed emissions that are single or multiple pulses.

Materials exposed to laser radiation can burn if energy levels are high enough and heat builds up sufficiently to start

CASE 21-1

1997, Japan. A man worked as a welder in an industrial plant for 20 years. He experienced intense pain in his left eye with continuous tearing while performing arc welding. At age 39, doctors diagnosed his medical problem as macular edema. Five years later his diagnosis was macular degeneration in the left eye. After two more years he had macular degeneration in the retina of the right eye. Macular degeneration most often occurs much later in life. His exposure involved near infrared and intense visible light that can affect the retina. Given his age, work exposure, and medical history, doctors concluded that arc welding had caused his disability.[a]

[a]www.jniosh.go.jp/en/indu_hel/pdf/IH_45_2_371.pdf

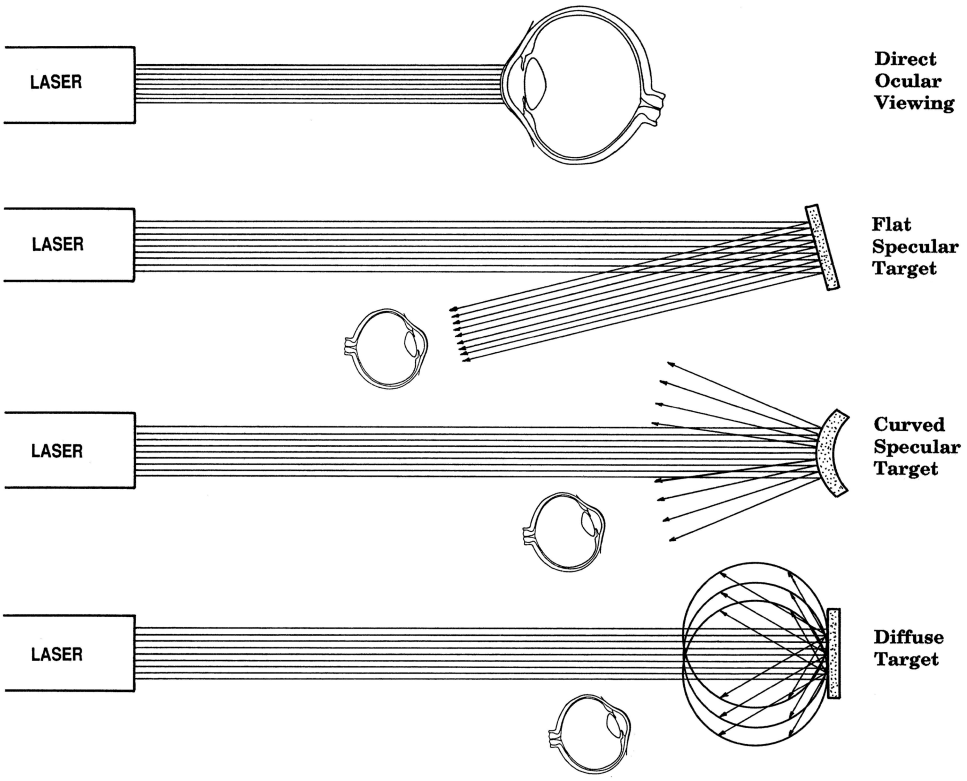


Figure 21-3. Laser radiation may be viewed (a) directly or (b) - (d) reflected. Reflected laser radiation may be (b) flat specular reflection, (c) curved specular reflection, or (d) diffuse reflection.

combustion. Lasers can cut or remove materials. Controlled local heating with laser beams in certain liquids causes the material to change state. Some machines apply this principle to create prototype plastic parts. The equipment cuts or removes material to form a shape out of a solid or liquid material. Medical applications use lasers to cut or remove tissue.

The hazards in lasers for people are essentially the same as for visible, ultraviolet, and infrared radiation. Lasers fall into the same wavelengths bands. Like other non-ionizing radiation, the greatest danger is to the eyes. Dependent on wavelength, damage may be to the cornea, lens, retina or other parts of the eye (refer to Figure 21-2). Dangers are greatest when someone views a beam directly. Usually, dangers are lower if someone looks into a reflected beam. As illustrated in Figure 21-3, properties of the reflecting surface may keep the beam essentially intact (specular reflection) or scatter the light (diffuse reflection). A polished, flat surface (like a mirror or window glass) reflects a beam with minimal absorption and little diffusion. Specular reflection of a laser light beam poses the greatest danger (Figure 21-4).

Potential damage to skin ranges from erythema (reddening) to blistering and charring. Compared to the region from 315 nm to 1 mm, effects to the skin are somewhat reduced in the 200–315 nm region.

A military classification system for laser hazards divides lasers into five categories.[16] Table 21-4 details this

CASE 21-2

March 2004, Berkeley, CA. A graduate student at the University of California sustained an eye injury from an Nd:YAG laser. While setting up an experiment one afternoon, the student strictly adhered to safety rules and wore proper protective eye wear. After dinner, he returned to collect some data. He didn't bother with eye wear because he felt that there were no exposed beams that posed a danger.

He made a slight adjustment in his experimental setup, saw a flash and heard a loud popping sound. He sustained a serious injury to his left eye. Months after the incident he still had some vision impairment.[a]

[a]http://mrl.illinois.edu/sites/default/files/pdfs/Spectra_March2005.pdf

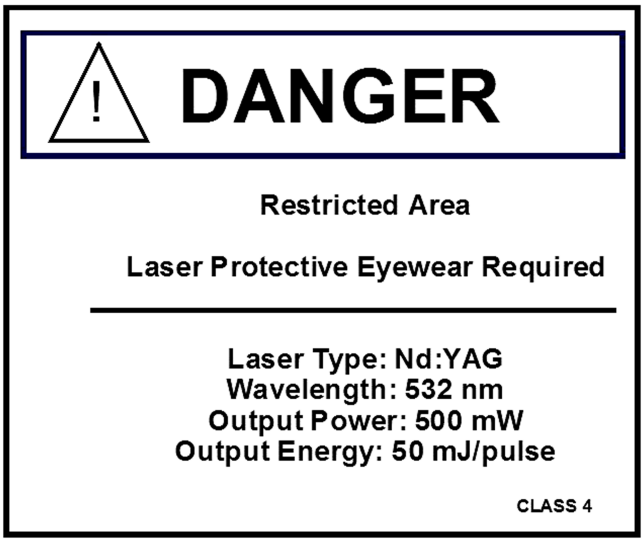


Figure 21-4. Example of a laser warning sign.

classification scheme together with a summary of hazards and Risks.

The U.S. Food and Drug Administration (FDA) regulates the manufacturing and sale of lasers. FDA also classifies lasers into six classes based on emission limits, wavelength, and other factors.[17]

Controls

The controls required depend on the class of laser. Controls may include the following:

- enclosure of the laser source,
- removal or reduction of potentially reflective surfaces,
- interlocks on doors to locations where lasers are in use,
- fail-safe pulsing controls to prevent accidental actuation,
- remote firing room and controls,

TABLE 21-4 Laser Device Classification and Risk Assessment

Class[a,b]	Energy	Hazard	Risk Assessment Matrix[c]
Class 1	Depends on wavelength. Example: AN/PAQ-4C, Infrared aiming light (830 nm) below 0.7 mW	Incapable of producing damaging radiation.	Effect: Negligible (IV) Hazard Probability: Unlikely (E) Risk Assessment: **LOW**
Class 2 (visible lasers only)	Depends on wavelength. Example: CW Helium neon alignment lasers: cannot exceed 1 mW	Eye protection is normally afforded by the aversion response (0.25 seconds for visible). Hazards comparable to projectors or the sun.	Effect: Moderate (III) Hazard Probability: Unlikely (E) Risk Assessment: **LOW**
Class 3 (3a (3R) and 3b)	Class 3a (Class 3R). Depending on wavelength: Between 1 and 5 times the Class 1 or Class 2 accessible emission limit (AEL). Example: Multiple Integrated Laser Engagement System (MILES) devices.	Direct and specular reflection viewing hazards. Diffuse reflection is usually not a hazard.	Effect: Moderate (III) Hazard Probability: Seldom (D) to Unlikely (E) Risk Assessment: **LOW to MEDIUM**
	Class 3b. Continuous wave (CW) and repetitively pulsed lasers: cannot exceed 0.5 W for 0.25 s. Example: Airborne Infrared Multipurpose (AM)-I/D, Infrared Aiming Light Pulsed lasers: Cannot exceed 0.030 Joule (C_A J/pulse or 0.125 J within 0.25 s) Example: Army Navy/Ground Vehicular, Visible Light, Fire Control (AN/VVG)-3, M1 laser rangefinder	Direct and specular reflection viewing hazards. Diffuse reflection is usually not a hazard.	Effect: Critical (II) to Catastrophic (I) Hazard Probability: Frequent (A) to Unlikely (E) Risk Assessment: **LOW to EXTREMELY HIGH**
Class 4	Average power above 0.5 W Pulsed lasers: Exceeds 0.030 C_A J/pulse or 0.125 J within 0.25 s Example: Ground Vehicular Laser Locator Designator (G/VLLD)	Direct and specular reflection viewing hazards. Diffuse reflection may present a hazard. May pose a fire hazard. May generate plasma radiation.	Effect: Catastrophic (I) Hazard Probability: Frequent (A) to Unlikely (E) Risk Assessment: **MEDIUM to EXTREMELY HIGH**

[a]See full publication for details: TB MED 524, *Control of Hazards to Health from Laser Radiation*, January 2006. (http://armypubs.army.mil/med/dr_pubs/dr_a/pdf/tbmed524.pdf)
[b]ANSI Z136.1.
[c]Army Field Manual 100-14, *Risk Management*, 23 April 1998.

- use of baffles to limit locations of beams,
- wearing of suitable protective eyewear and clothing.

Other controls include warnings, training of users including service and maintenance people, and medical surveillance of users. Where lasers present dangers, use warning signs and alarm systems. Dangerous laser devices must have warning labels. Figure 21-4 provides an example of a laser warning sign.

Operators must learn how to operate laser systems correctly and safely. The training should include procedures to avoid pointing lasers where other people might pass. Training involves controlling access to the location where lasers are in use. People who do not operate laser systems but work with teams using them must learn proper procedures. They must learn the hazards the systems present. Training must address protective eyewear or clothing and their use.

Medical surveillance includes eye and vision examinations and proper selection of protective eyewear and clothing.

The equipment itself and an operation present other hazards that must be controlled. Electrical hazards must have grounding, compliance with electrical codes and lockouts for maintenance and servicing. Where lasers vaporize material in machining, there is often a need for ventilation to prevent breathing contaminated air. If lasers cause materials to fly, such as in cutting and machining operations, there is a need for guarding to contain the flying particles. Ionizing radiation from some lasers requires proper shielding. Cryogenic systems to cool lasers require proper design. Workers need training to operate and maintain them while preventing injury from the extremely cold coolants.

When selecting controls related to the safety of lasers, some implement a factor of safety when deciding on appropriate levels of controls.

Standards

The U.S. Army publication Technical Bulletin Medical 524 (Note 16) identifies maximum permissible exposures (MPE). The MPE is the level of laser radiation exposure allowed without hazardous effects or adverse biological changes to the eyes or skin. Because exposures at the MPE may be uncomfortable to view or sensitive to the skin, actual exposure levels should be as far below the MPE as possible.

The Laser Institute of America (LIA) through ANSI publishes standards[18] on the safe use of lasers in various settings. The American Conference of Governmental Industrial Hygienists also publishes exposure standards for lasers. In addition, there are international standards for laser safety.

Measurement

The measurement of laser radiation is expensive and difficult to make. Manufacturers normally certify the source energy and wavelengths emitted from lasers. These data allow others to recognize hazards and establish suitable controls for a manufacturer's laser systems.

21-7 OTHER NON-IONIZING RADIATION

There are devices and systems that employ or emit non-ionizing radiation for which there are no consensus standards for safety. In some cases little is known about specific dangers to people. This is especially true for extended periods of exposure at levels that are below immediate injury levels. Some devices are in wide use and draw public concern.

One example is widespread use of cell phones in the general population including among children. As already noted, cell phones involve microwave radiation. The public concern for some is whether holding a cell phone close to the head will lead to cancer or some other long exposure health issue. Medical studies continue to expand the body of knowledge. Based on current knowledge, the FCC has set energy limits for cell phones. Another option is using listening devices that link to a cell phone and move the radiation source away from the head.

Another example that generates some public fear is the widespread use of monitors or visual display terminals (VDTs) in office automation. Compared to early analog models, current digital models have lower emission levels. The radiation from monitors is just one potential hazard related to their use. Glare, reflected glare, size of images and print and other factors may contribute to vision and other worker issues.

Workers in high energy non-ionizing radiation environments may be at risk. Examples of workers are power station operators, aluminum workers, power and telephone linemen and other workers chronically exposed to electric and magnetic fields. The American Conference of Governmental Industrial Hygienists monitors current literature in developing and updating its exposure recommendations.[19]

Studies continue to pursue whether there are health risks related to long-term exposures. Recent studies evaluated extended exposures to non-ionizing radiation. Some studies on rats give evidence that extended exposures to microwaves contribute to development of cancerous tumors. Statistical studies suggest increased rates of leukemia. As yet, results of such studies are not conclusive regarding harmful effects to humans.

The main basis for the current microwave standard is effects in tissue. Other biological effects are under investigation. Not all effects are harmful; some are beneficial. Incorporation of new information into exposure recommendations and standards is a slow process.

Low Frequency Electric and Magnetic Fields

For a period in the 1980s there was significant attention on low frequency electric and magnetic fields. Extremely low frequency (ELF) wavelengths are power transmission frequencies (50–60 Hz) and below. They can occur around extra high voltage (EHV) transmission lines. They also occur in special radio transmission frequencies that penetrate underwater for submarine communications. There are also many non-transmission sources for power frequency fields, such as wiring in walls, appliances and lighting fixtures.

Public concern over power transmission lines initially involved aesthetics of towers, property right-of-way issues, and property values. Also there were nuisance effects, such as interference with radio and television reception and audible noise. Some experienced induced shocks that occur when a person standing beneath an EHV line touches a large ungrounded metal object, such as a truck or farm vehicle. Scientific and medical literature first noted potential health effects in the early 1970s. Under certain circumstances, the membranes of cells are sensitive to even weak externally imposed low frequency electromagnetic fields. Such radiation can trigger biochemical responses. A government sponsored review of the ELF health effects literature found the existing information complex and inconclusive. However, there are effects at the cellular level and epidemiological evidence identifies some concern about risks from chronic exposure. The World Health Organization (WHO) summarizes findings.[20]

EXERCISES

1. A microwave oven has a 6 GHz source. If the energy incident on the inside of the door is 200 mW/cm^2 and the door has a 32×32 mesh screen, what is the energy level passing through this screen?
2. Download a copy of U.S. Army Technical Manual Medical 524, especially the appendix with Maximum Permissible Exposures (MPEs). Using this standard, answer the following:
   (a) A worker/soldier receives a direct ocular exposure to a laser. Determine if the MPE is exceeded for each of the following exposures:

	Wavelength	Time	Irradiance
(1)	307 nm	10 s	28 ml/cm^2
(2)	410 nm	15 s	10 ml/cm^2
(3)	800 nm	1.5 s	10 mJ/cm^2
(4)	560 nm	200 s	15 mJ/cm^2

   (b) A worker/soldier receives skin exposure to a laser beam. Determine whether the MPE is exceeded for the following conditions:
   Wavelength = 1200 nm
   Exposure time = 1×10^{-8} s
   Irradiance = 0.5 J/cm^2.

REVIEW QUESTIONS

1. Which forms of non-ionizing radiation are
   (a) absorbed by the cornea of the eye?
   (b) pass through eye tissue?
   (c) absorbed by the lens of the eye?
   (d) absorbed by the retina of the eye?
2. Compared to other body tissues, why is the eye highly susceptible to damage from nonionizing radiation?
3. What are three effects of microwaves on humans?
4. What controls will limit exposures to microwaves?
5. What dangers does ultraviolet radiation pose?
6. What are the three bands of UV radiation? Which poses the greatest danger?
7. What dangers do exposures to infrared radiation pose?
8. What controls reduce or eliminate UV and IR dangers?
9. What dangers does high intensity visible light pose?
10. What controls limit dangers from high intensity visible light?
11. What dangers do lasers pose?
12. What parts of the body are most susceptible to laser injury?
13. What controls reduce the hazards of lasers?
14. What are possible dangers associated with computer monitors?
15. Explain each of the following:
    (a) Non-ionizing radiation
    (b) SAR
    (c) TLV
    (d) Photokeratitis
    (e) Basal cell carcinoma
    (f) SPF
    (g) LASER
    (h) CW laser
    (i) MPE
    (j) VDT
    (k) ELF
    (l) EHV

NOTES

1 Public Law 90-602, *Radiation Control for Health and Safety Act of 1960.*

2 www.fda.gov/ICECI/Inspections/InspectionGuides/ucm071626.htm

3 29 CFR 1910.97. www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9745)

4 *Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment*, American Conference of Government Industrial Hygienists (ACGIH), Cincinnati, OH, annual update.

5 www.fcc.gov/oet/rfsafety/rf-faqs.html

6 www.fcc.gov/encyclopedia/specific-absorption-rate-sar-cellular-telephones; www.fcc.gov/guides/human-exposure-rf-fields-guidelines-cellular-and-pcs-sites; www.fcc.gov/encyclopedia/radio- frequency-safety

7 http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=1626482

8 www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=1030.10

9 www.arpansa.gov.au/pubs/rps/rps3.pdf

10 www.fda.gov/forconsumers/consumerupdates/ucm258416.htm

11 "Permissible Limit for Continuous Ultraviolet Exposure," *Council on Physical Therapy*, American Medical Association, Chicago, IL, 1948.

12 *Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment and Biological Exposure Indices with Intended Changes*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, annual update. (Note: This publication is updated annually and standards in it may change.)

13 www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=1040.20

14 www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=1040.30

15 www2.epa.gov/sunwise/uv-index

16 Department of the Army, Technical Bulletin Medical 524, 31 January 2006. http://armypubs.army.mil/med/dr_pubs/dr_a/pdf/tbmed524.pdf

17 21 CFR 1040.10 (http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?FR=1040.10)

18 ANSI Z136 Series (Z136.1 through Z136.9) on safe use of lasers. (https://www.lia.org/store/ANSI+Z136+Standards)

19 *Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®)*, ACGIH, Cincinnati, OH, annual update.

20 http://www.who.int/peh-emf/publications/facts/fs322/en/

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CHAPTER 22

IONIZING RADIATION

22-1 INTRODUCTION

Ionizing radiation can draw a considerable emotional response from the public. Major events involving ionizing radiation stir public concerns. Many factors contribute to this response. There are fears developed from the devastation of atomic bombs dropped on Japan in World War II.[1] There is fear of potential use of atomic weapons by the military and terrorists. There is fear of cancer and other health effects from ionizing radiation exposures.

Also, there are economic concerns. There are concerns over long-term dangers from some isotopes. Often there are fears because of a lack of understanding about positive ionizing radiation uses. There are concerns over management of waste, hazardous releases from power plants and plant decommissioning. News events contribute to public concerns and opinions that heighten the public debate.

However, there are also several useful applications of ionizing radiation. For example, X-rays, gamma rays and other forms of ionizing radiation are part of medicine and dentistry and have been for decades. Ionizing radiation has valuable uses in testing the effectiveness of welds and other applications.

This chapter discusses the safety aspects of ionizing radiation, not the public issues. It explores the basics of ionizing radiation and the hazards and controls for it. However, readers should perform an evaluation of this complex subject on their own. They should separate the emotional elements involved before forming their own opinions about ionizing radiation and its applications. Knowledge of major events involving ionizing radiation helps form opinions.

22-2 PHYSICS OF RADIATION

Ionizing radiation is any electromagnetic or particulate radiation capable of producing ions when it interacts with atoms and molecules.

Types of Radiation

The main types of ionizing radiation are X-rays, gamma rays, alpha particles, beta particles, neutrons, and other high energy particles.

Alpha Particles Alpha particles have the same structure as the nuclei of helium atoms: two protons and two neutrons. Relative to other forms of ionizing radiation, alpha particles are large. They have little penetrating power. A piece of paper or the outer layer of skin can stop them.

Beta Particles A beta particle is an electron (negative charge) or positron (positive charge) separated from the nucleus of an atom. Smaller than alpha particles, beta particles travel at higher speeds and have enough penetrating power to pass through nearly ¼ in. of human tissue.

Gamma Radiation Gamma radiation is not a particle. It is energy waves in the electromagnetic spectrum. During radioactive decay, certain materials emit gamma rays from the nucleus of decaying atoms. Gamma rays have much greater penetrating power than beta particles and are best stopped by dense materials.

X-rays X-rays are similar to gamma rays. They are energy waves generated from outside the nucleus of an atom during decay or by impact from external electrons. X-rays have penetrating powers similar to gamma rays.

Neutrons Neutrons are particles with high mass and no charge. They are not produced spontaneously. Nuclear reactions produce them. Neutron energies are classified as slow, medium, and fast. Because neutrons readily penetrate matter, there is a need for high density materials containing high levels of hydrogen atoms to stop them.

Sources of Radiation

Natural Radiation There are two main sources of ionizing radiation: natural and artificial. Natural radiation sources include cosmic and gamma radiation found in certain soils. Building products made from these radioactive soils also give off natural radiation. Natural radiation is also present in some ingested food and water and some inhaled air. Natural exposures vary considerably by geographic location.

Natural radiation sources create both external and internal exposures. External exposures are those arriving at the outside of a human body. Internal exposures are those received on internal tissue through ingested and inhaled

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 22-1

22-1a

March 28, 1979, Three Mile Island, PA. On March 28, 1979 an accident sequence took place at the Three Mile Island Unit 2 nuclear power facility. Widespread media attention, investigations and a presidential commission (the Kemeny Commission) focused national attention on this event for a long time. The commission report[a] cited many contributing factors, including operator error, lack of training, complexity of the failure, multiple concurrent failures, lack of information to operators, and design deficiencies in the control room. In addition, there was a bureaucratic snarl that withheld information about a similar malfunction at another plant. Among the released materials were 15 Ci of ^{131}I. Much has been written about the accident. One article summarized the events in the control room and the many design issues from a human factors perspective.[b]

22-1b

April 26, 1986. Chernobyl, Ukraine. On April 26, 1986, the nuclear power plant at Chernobyl, in the northern Ukraine region of the Soviet Union, exploded. The explosion killed several people. Authorities evacuated more than 100,000 people. Many received treatment for radiation or died. The incident released more radioactive iodine and cesium than from all nuclear bombs and atmospheric testing since 1945. Airborne radioactive iodine and cesium contaminated large portions of Europe. The explosion produced much international public discussion. The focus was on resulting dangers from low-level exposures, cleanup costs, and responsibilities across national borders. By 2000, funding from many parts of the world started a cleanup of the remaining plant. Following the accident, large quantities of concrete filled the plant to isolate the out-of-control reactor. Chernobyl and miles around it remain closed to public access because of the high levels of radiation. Again, much has been written on the accident and its aftermath.[c,d,e]

22-1c

March 11, 2011, Fukushima, Japan. A near-record earthquake with a 9.0 magnitude occurred off the northeast coast of Japan. It produced a nearly 50-foot high tsunami that flowed over protective walls, killed more than 19,000 people and destroyed or collapsed more than one million buildings.[f] The nuclear reactors at Fukushima withstood the earthquake, but not the tsunami. Within three days, three reactor cores had melted. Within a few months, the plant lost other parts also. The event cause a release of large amounts of radiation. Officials evacuated more than 100,000 people from their homes to prevent radiation sickness.[g] The cleanup continued for many months.

[a] http://www.pddoc.com/tmi2/kemeny/

[b] B. SHERIDAN, "Human Error in Nuclear Power Plants," *Technology Review*, February: 23–33 (1980).

[c] www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1250/

[d] www-pub.iaea.org/MTCD/publications/PDF/Pub913e_web.pdf

[e] www-pub.iaea.org/mtcd/publications/pdf/pub1239_web.pdf

[f] www.cnn.com/2013/07/17/world/asia/japan-earthquake—tsunami-fast-facts/

[g] www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Fukushima-Accident/

materials. People in the United States receive an estimated 125 mrem of natural radiation per year. Of that, about 100 mrem is external and 25 mrem is internal.

Artificial Radiation Artificial sources that expose the general population include certain consumer products, medical procedures, occupational sources, and general environment sources. Products with ionizing radiation include analog television sets and computer monitors, some smoke detectors, luminous dials on clocks, and luminous signs. Medical sources are gamma, beta, and X-rays for diagnostic and treatment procedures. Occupational sources involve jobs related to manufacturing of products with radiation sources. Also, there are medical service positions, certain research work, mining, and production of radioisotopes and nuclear fuel and weapons. In addition, transportation and waste handling involve radioactive materials. There are exposures during normal job functions and exposures during accidental releases.

Units of Measure

There are several kinds of measures related to ionizing radiation. Some measures address physical characteristics. Others assess biological effects. There are measures for

converting physical measures to units of biological effects. There are also measures that express the amount of ionizing radiation absorbed by an exposed person.

Physical The energy level of ionizing radiation is measured as megaelectron volts (MeV). The amount of ionizing radiation released by a material regardless of the type of radiation has the measure curie (Ci) in British Units. In metric units the measure is becquerel (Bq). A curie (Ci) is the amount of radioactive material that has a disintegration rate of 3.7×10^{10} atoms/s.

The amount of radiation traveling through the air, an exposure, has units of Roentgen (R). It is a measure of the ionization produced in air by X-rays and gamma rays.

Radioactivity decays exponentially with time. The time required for a material to lose half of its radioactivity is the half-life. Tables of physical properties of radioactive materials list their half-life values. A material that has some radiation level at one point in time will have one half that radiation level after one half-life. Some materials decay quickly and have half-life values of days or less. Carbon-14 decays slowly and has a half-life of 5730 years. Uranium-238 is both radioactive and very toxic. It has a half-life of 4.5 billion years.

Radiation Dose The amount of radiation absorbed by an object or person is the absorbed dose. The absorbed dose for a person per unit of tissue mass is the rad (radiation absorbed dose). The dose corresponding to the absorption of 100 erg/g of tissue is 1 rad. The metric unit for radiation absorbed dose is gray (Gy). A millirad (mrad) is one-thousandth of a rad. Absorption may occur over the whole body or in local tissue.

Biological Effects and Dose Equivalence Radiation produces biological effects on the human body. Different types of radiation produce effects at different rates. Dose equivalent or effective dose combines the amount of radiation absorbed and the medical effects for a type of radiation. Units of biological effect are Rems (roentgen equivalent man). The metric unit is sievert (Sv). For example, the effect produced by a dose of 1 R of X-rays is 1 rem. Some dose equivalents are much lower and measured in millirems (mrem).

The body absorbs different types of radiation at different rates. As a result, different materials need different doses to produce similar biological effects. The relative biological effect (RBE) is the measure of biological effect (rem) divided by the dose (rad). Table 22-1 lists doses necessary for equivalent biological effects.

TABLE 22-1 Dose Equivalents for 1 rem of Radiation

Dose (rad)	Type of Radiation
1	1 R of gamma rays or X-rays
1	X-rays, gamma rays, or beta particle radiation
	Neutrons and high energy protons
0.05	Particles heavier than protons and with sufficient energy to reach the lens of the eye

22-3 HAZARDS

Exposure to radiation may produce a variety of effects in man. Damage is a function of the type of radiation, dose, the tissue and organs exposed, and age. In general, radiation affects rapidly developing cells most. This makes radiation therapy useful for rapidly growing cancer cells. It also makes radiation dangerous for infants and children who have many rapidly developing cells.

Some organs concentrate radioactive materials. For example, iodine concentrates in the thyroid gland. This phenomenon offers physicians a treatment for hyperthyroidism (overactive thyroid) using radioactive iodine. The radioactive iodine destroys thyroid tissue as it concentrates in the thyroid.

Another example is concentration of strontium-90 by mammary glands. Cows that consume food contaminated with ^{90}Sr produce highly contaminated milk. Strontium-90 has a long half-life and becomes a more persistent contaminant than other radioactive materials, such as Iodine-131, which has a short half-life.

Calcium, strontium-90, and radium-226 have similar chemical properties. The result is that strontium and radium in the body tend to collect in calcium-rich areas, such as bones and teeth. They contribute to bone cancer.

High dose rates are usually acute exposures rather than continuous, chronic exposures. Their effects include ulceration of skin and intestinal tissue and reductions in white cell production. Symptoms of acute radiation sickness are weakness, sleepiness and eventually stupor, tremors, convulsions, and death. Symptoms may include nausea, vomiting and diarrhea, loss of hair, and bleeding. Death may occur after one or two days or have delays of several weeks.

Low dose rates may be acute or chronic. There are often delays in effects for low dose rates between exposure and measurable effect. There may be damage to cell structure and function and cells may die. Low levels may produce reddening of skin or damage internal organs. Ionizing radiation may produce genetic effects, leukemia and other cancers, cataracts, and reduction in life span. Statistical studies of populations form the basis for knowledge of low-level effects.

For whole body radiation the most critical organs and tissues are the lens of the eye, the blood-forming organs (red bone marrow), and the gonads. Internal radiation sources may affect several vital organs.

Linearity No-Threshold Theory of Radiation Risks

High dose rates, on the order of 500–600 rems, will prove fatal to about half an exposed population. At the other extreme,

CASE 22-2

1920s to 2000s, East Orange, New Jersey and Ottawa, IL. The invention of luminous paint occurred in Europe in the 1870s. When exposed to light, it remained luminescent for some time. In the late 1910s, the paint found use in luminous dial clocks and watches. It soon expanded to dials for aircraft instruments.

Women factory workers primarily applied the paint to the dials using fine, camel hair brushes. To get the paint brush tip very fine, many workers touched the brushes to their lips and tongues between strokes. By the mid-1920s, serious medical and dental cases appeared. The tooth sockets of extracted teeth failed to heal. Jaw bones began to deteriorate and disintegrate. Treatments were not effective. Some workers with such health problems soon died. The workers became known as the "Radium Girls."[a]

The cases led to many studies and scientific and medical opinions. Victims filed lawsuits. Owners using luminous paint in their companies sold them to others who continued the work. The cases became complex, even after plants were closed. Demolition and disposal continued to 2009 and beyond, involving numerous buildings contaminated with radiation.

[a]Ross Mullner, *Deadly Glow: The Radium Dial Worker Tragedy*, American Public Health Association, 1999.

people receive low-level radiation from natural and other sources throughout their lifetime. Statistical studies have compared effects of low-level exposures for the general population. However, it is difficult to estimate the actual effect. In some kinds of exposures the main concern is some form of cancer. The time between the period of exposure and the appearance of disease is as long as 30–40 years. Consequently, the probability of effect for low dose exposure is often unclear.

Some scientists argue that effects from high-level radiation exposures are useful in estimating effects from low-level exposures. They argue that the effects have a linear relationship to dose rate. Some argue there is no lower threshold of exposure for which there is no effect. This is the linearity hypothesis or linear no-threshold theory (LNT) of radiation risks. For convenience in estimating effects, LNT extrapolates the effects at high levels to effects at low levels. The effects lessen at lower levels. For example, LNT suggests that the likelihood of dying from cancer increases with exposure. Scientist do not agree on LNT for predicting effects from low-level exposures.

Studies of effects became more controversial in 198l when there was a recalculation of data from the explosions at Hiroshima and Nagasaki. The recalculations suggested that many cancers in that population had resulted from low energy gamma rays. Previous studies had suggested that high energy neutrons and protons were the primary forms of radiation at those locations. The recalculations suggested that low energy forms of radiation were more dangerous than previously thought.[2]

22-4 EXPOSURE STANDARDS

In general, standards for ionizing radiation assume that the effects are cumulative. Therefore, exposure limits include a period of exposure. A single, acute exposure or repeated exposures over an extended time can exceed the limit. Several organizations have exposure standards.

Table 22-2 gives a summary of exposure standards from some federal agencies. Some agencies have adopted standards more stringent than standards listed in Table 22-2.

Beside exposure standards, there are standards for emissions from electronic products[3] and emissions from nuclear power plants.[4] There are also standards for transportation, marking, and packaging of radioactive materials.[5]

22-5 CONTROLS

There are several types of engineering controls to limit dangerous exposures to radiation. Controls include limiting radiation emissions at the source, limiting time of exposure, extending the distance from a source, and shielding. Certain other controls will also help prevent dangerous exposures.

Limit Radiation Sources

The best way to prevent radiation exposure is to limit the amount of radiation from a source. Limiting the quantity and type of ionizing material achieves this goal.

Time

Another method for minimizing risk to people is to limit the duration of exposure. One can prevent access to locations where radiation sources exist, which prevents unnecessary exposures. Procedures can also limit the duration of exposure. Exposure limits assume cumulative amounts over a period of time. Because people cannot sense radiation, there is a need to use measurement instruments and dosimetry. Measurement

TABLE 22-2 Exposure Limits* for Ionizing Radiation

Exposure	Limit	Source
OSHA		
Whole body: head and trunk; active blood forming organs	1.25 rem per calendar quarter	OSHA[a]
1.25 rem per calendar quarter lens of eyes; gonads		
Hands and forearms; feet and ankles	8.75 rem per calendar quarter	OSHA[a]
Skin of whole body	7.5 rem per calendar quarter	OSHA[a]
Individuals under 18 yr of age	1/10 of above limits	OSHA[a]
NRC		
Occupational dose limits for adults		
Total effective dose equivalent	5 rems/year	NRC[b]
Lens dose equivalent	15 rems/year	NRC[b]
Shallow-dose equivalent for skin of whole body or skin of any extremity	50 rems/year	NRC[b]
For minors	1/10 of adult doses	NRC[c]
Individual members of the public from a licensed operation	0.1 rem/year	NRC[d]
EPA		
Drinking water:		
Radium-226 & Radium-228 combined	5 pCi/l	EPA[e]
Gross alpha particles	15 pCi/l	EPA[e]

*Standards are subject to change at any time.
[a]29 CFR 1920.1096
[b]10 CFR 20.1201
[c]10 CFR 20.1207
[d]10 CFR 20.1301
[e]40 CFR 141.15

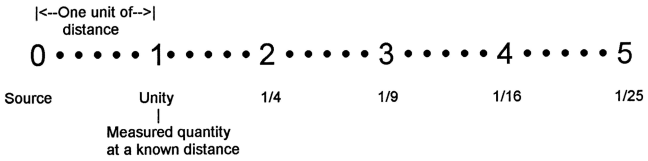


Figure 22-1. Radiation decreases with the square of the distance from a source.

instruments assesses quantity. Dosimetry incorporates the duration of exposure. Dosimetry devices typically are pinned to an individual's clothing. A person wears them and turns the devices in at a specified time. The device is checked with an instrument to assess cumulative exposure.

Half-life properties can help limit exposure time if the half-life is very short. Many radioactive materials have half-life values that are too long to use the property to limit exposures.

Distance

Radiation levels decrease with the square of distance from the source. This is the inverse square law for radiant energy sources and materials. As shown in Figure 22-1, a person at one unit of distance from a source has some level of radiation exposure. At double the distance, the amount of radiation will be one fourth that of the first location.

The level of radiation I_r is

$$I_r = 1/n_d^2 \tag{22-1}$$

where n_d is the number of distance units relative to some reference location.

Distance is an appropriate solution for certain kinds of exposures. For example, distance helps to reduce external exposures. Distance has little or no value for internal exposures.

CASE 22-3

June 1985 to January 1987, Georgia, Texas, Washington State and Ontario, Canada. Medical centers used Therac-25, a machine that uses radiation treatments for cancer. In thousands of procedures, the machines provided the correct radiation dose. Typical radiation treatments involve doses up to about 200 rads. A dose of 500 rads proves fatal in 50% of the cases. In six cases, however, the machine delivered doses in excess of 15,000 rads, killing five patients.

Earlier models for the machine used interlock circuits to ensure the safety of the system. In this model, a computer and software controlled the process, including a check to prevent possible harm. The machine had two modes. An electron mode irradiated the patient directly. An X-ray mode involved much higher electron intensity to generate the desired rate of X-rays. The software was the only check to make sure the latter mode was correctly in place.[a]

While a variety of factors contributed to the sequence of deaths, one report identified several requirements for incorporating safety into software design and use that control systems. There are numerous reviews of these cases and the issues surrounding safety in software design.

[a]http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.96.369&rep=rep1&type=pdf

Example 22-1 A dental technician takes X-rays of patients' teeth. The control cord for the X-ray machine allows the technician to stand 3 ft away. If the control cord were longer and allowed the technician to stand 9 ft away, what reduction in radiation level would result?

Applying Equation (22-1) and assuming the exposure level for the initial position to be unity, the radiation at the new location would be $I_r = 1/(3)^2 = 1/9$ of the first position.

Shielding

Reducing radiation levels with shielding is another form of protection. Shielding effectiveness, the ability of a specific material to attenuate radiation, varies with different forms of radiation. For example, to some extent, air attenuates low energy beta waves, but it has little effect on other forms of radiation.

Shielding effectiveness varies with the shielding material. The unit of measure for the attenuation properties of materials is half-value thickness. One half-value thickness will cut the energy level of radiation arriving at the material to one half as it leaves the material after passing through it. The amount of radiation absorbed, R_a, and the amount transmitted, R_t, are given by

$$R_a = R_0[1 - (1/2)^n] \quad (22\text{-}2a)$$

$$R_t = R_0(1/2)^n \quad (22\text{-}2b)$$

where

n is the number of half-value thicknesses

R_0 is the amount of arriving radiation

Published tables give attenuation properties of materials. Table 22-3 contains selected attenuation properties.

TABLE 22-3 Radiation Absorption Properties of Selected Materials

Material	Radiation Type	Half-Value Thickness	Attenuation Coefficient
Concrete	^{137}Cs	1.9 in.	
	^{60}Co	2.6 in.	
	^{198}Au	1.6 in.	
	^{192}Ir	1.7 in.	
	^{226}Ra	2.7 in.	
Lead	^{137}Cs	0.65 cm	
	^{60}Co	1.20 cm	
	^{198}Au	0.33 cm	
	^{192}Ir	0.60 cm	
	^{226}Ra	1.66 cm	
Steel	^{137}Cs	0.64 in.	
	^{60}Co	0.82 in.	
	^{192}Ir	0.50 in.	
	^{226}Ra	0.88 in.	
Water	Neutrons	9.25 cm	0.602/cm

Example 22-2 One foot of water shields neutrons at 60 MeV. By what percent is the energy level of the neutrons reduced? What radiation level passes beyond the water shield?

From Table 22-3 the half-value thickness of water for neutrons is 9.25 cm. The number of half-value thicknesses for one foot is (30.48 cm/ft × 1 ft/9.25 cm) = 3.295 half-value thicknesses. The attenuation of the shield is $1 - (1/2)^{3.295} = 1 - 0.102 = 0.898$ or 89.8% reduction. The radiation level leaving the shield is 60(0.102) = 6.11 MeV.

Barriers

Barriers can protect many radiation sources. For example, walls or fences around operations involving radiation sources will keep people out who should not be there. Liners under holding ponds of contaminated waste will prevent leaching into soil streams or groundwater. The liners are effective as long as there is no leak in the liners.

Other Safeguards

There are many other methods that help prevent or reduce exposures to radiation sources. Warnings, a variety of procedures, security systems, alarm systems, training of personnel, and analyzing systems for potential failure modes are some methods. ANSI standards and regulations provide detailed guidance for many of these safeguards.

Warnings Warnings should mark locations and equipment where there are ionizing radiation sources. Figure 22-2 shows the standard ionizing radiation symbol. Packaging and

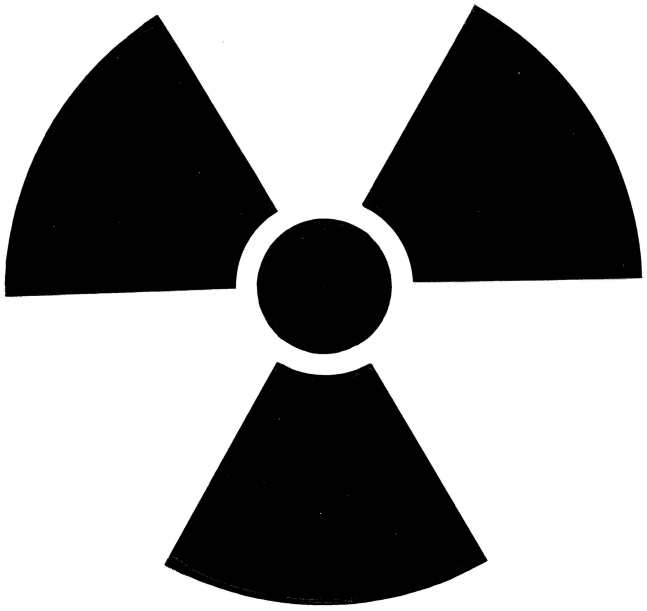


Figure 22-2. Standard radiation symbol.

labeling of radioactive material require showing this symbol as well. Visual warnings, such as flashing lights, and audio signals help people in an area recognize when there is a danger associated with radiation operations. The warnings may also be audible to warn of any dangerous presence or level of radioactive material.

Evacuation Should there be a significant release of radioactive material that endangers people in a facility or the public located outside a facility, it is important to lessen their chance of exposure. Nuclear Regulatory Commission (NRC) and other regulations require evacuation plans for accidental releases. Plans that have rehearsals are more effective when executed for an actual release situation.

Security Should radioactive material get into the wrong hands, there is a danger of exposure to numerous unknowing people. This has happened with medical materials. Security should prevent materials from getting into the hands of criminals who can use it for a terrorist threat. Contaminated materials can become part of other products and expose manufacturing workers, truckers, and buyers of the products.

Procedures play a major role in controlling the entry or exit of radioactive material from sites. Typical procedures include security, physical monitoring, and manifest systems. Security procedures and physical security systems can also prevent unauthorized persons from entering a facility or entering dangerous locations.

Dosimetry Because one cannot sense radioactive material, it is essential to monitor exposures of the people who work with and around such material. Section 22-6 describes various measurement methods.

Training People who work with and around radioactive material need training to understand the hazards of ionizing radiation. They need to understand how to protect themselves and what procedures to follow. They need to develop skills in performing activities correctly and to know the value of protective clothing and other protective means.

The public and people responsible for the public need training to deal with emergencies involving radioactive materials. If there are evacuation plans, police and other emergency organizations need to know what to do. They must have skill in completing assignments.

Complex systems involving radioactive materials often have a simulator, which allows trainers to create a variety of situations for teaching operators and others how to react, make decisions, and act correctly and safely.

System Design and Analysis In operations and facilities involving radioactive material there is seldom the luxury of waiting for things to go wrong. Analytical techniques, such as those described in Chapter 36, are useful for anticipating what might go wrong. A notable study of nuclear power plant failures[6] applied such methods. Although failures in such complex systems are difficult to predict and foresee, such methods are essential in ensuring safety.[7]

22-6 MEASUREMENT

Instruments

Instruments for measuring ionized radiation typically include a sensing device and a readout device. Some are useful for field measurement whereas other combinations come in small packages useful for dosimetry. Sensors are very critical. Different types of radiation require different types of sensors. Sensors include Geiger-Mueller tubes (used in Geiger counters), ionization chambers, luminescent detectors, scintillation detectors, and photographic emulsions.

CASE 22-4

November 1983, Juarez, Mexico. Two individuals removed a discarded radiation therapy machine containing 1,000 or more cobalt-60 pellets. The pellets spilled into the bed of their pickup truck. They sold the machine at a local scrapyard for $10. A short time later, the truck battery died. They left it parked for seven weeks. People often hung around the truck in conversation.

Many pellets remained in the machine and got mixed in the steel recovered by the scrap yard. The scrapyard sold the metal. One foundry that purchased some of the scrap steel used it to make steel rebar for construction. Another used the scrap steel to make pedestal legs for restaurants.

Later a truck carrying the rebar entered a gate at the Los Alamos National Laboratory in New Mexico. The load set off radiation alarms. Soon investigators traced the contaminated rebar to the foundry and the contaminated pickup truck.

During the entire episode, numerous people unknowingly received significant cobalt-60 radiation doses. At least four people received exposures of at least several hundred rad. Two scrapyard workers became sterile. Some faced increased risks from cancer. No one died.[a]

[a]www.orau.org/ptp/collection/accidents/juarez.htm

A Geiger-Mueller tube is a gas-filled chamber used to measure alpha, beta, and gamma radiation. Radiation entering the tube ionizes the gas and creates small currents that the instrument measures.

Ionization chambers measure beta, gamma, and X-rays using a charge placed on an electrode in a tube. Radiation ionizes the air surrounding the electrode and allows charge to leak away. The amount of charge lost correlates with the amount of radiation arriving at the chamber. A common dosimetry device is a pocket ionization detector.

Luminescent detectors measure exposures to neutrons. Arriving radiation changes the energy content of solids in the detectors. The energy change causes them to emit light. The amount of light is proportional to the energy change.

In scintillation detectors, incoming radiation strikes a thin layer of crystals or a solution of organic materials that produce light. Light output is proportional to the radiation absorbed. These devices measure alpha, beta, gamma, and slow neutron sources.

Radiation-sensitive photographic film detects gamma and X-rays. The radiation affects the emulsion similar to light. When compared to standards, the developed films establish the radiation exposure. A common dosimetry device using this method is a film badge.

Surveys

OSHA and other agencies require the surveying of potentially occupied areas to determine if they comply with regulations and standards for ionizing radiation. A survey may include background readings for radiation with follow-up readings at various times. A survey may also include analysis of operations and methods for each area of concern.

Dosimetry

One must monitor the exposure for each worker potentially involved with ionizing radiation. Visitor exposures are also important. OSHA and other organizations require such records. Typically, individuals wear film badges, pocket ionization detectors or other instruments while in areas where there are possible exposures. There are record for exposures. Employers must retain records for each person.

22-7 RADON

Radon is a colorless, odorless, and radioactive gas that comes from the complex decay of uranium. It occurs naturally in many locations in soil, rock, and water. It often appears in mines and ore tailings. The decay products of radon, called radon daughters, emit alpha, beta, and gamma radiation. Most of these products have very short half-lives. In the late 1980s, radon gained much national attention and programs to map the presence of radon in homes and buildings spread across the country. The concern resulted from recognition that radon gas can accumulate in houses and other buildings. Occupants may inhale a variety of decay products over extended periods. Concentrations may build within buildings to levels considered dangerous. They could contribute to increased lung cancer rates.

Current standards recommend radon levels of 4 pCi/l or less. Methods to prevent buildup of radon concentrations include ventilating crawl spaces, drain tiles in foundations and other locations. Assessment of construction sites for radon and control methods for radon are an important element of facility design and real estate transactions.

22-8 IRRADIATED FOOD

A potentially useful application of radiation is in food preservation. Irradiating food can prevent spoilage, kill organisms that cause food-borne illness and extend shelf life.[8] The food industry has known about these procedures for some time. They are in limited use for certain foods. Astronauts consume irradiated foods in space to prevent digestive problems. The FDA has standards for the production, processing, handling, and packaging of irradiated food.[9] However, some of the public do not want irradiated food products. There is pressure to improve labeling to identify when a product has undergone irradiation.

EXERCISES

1. A hospital laboratory uses a gamma radiation source, Radium-226. If shielding is considered as a means of control, how many inches or centimeters are needed to reduce the radiation level to 1% of what a worker would be exposed to without shielding? Assume the shielding material is:
   (a) concrete
   (b) steel
   (c) lead
2. An alternative to Exercise 1 is to extend the distance between the radiation source and the worker. The initial design placed the worker 2 ft from the source. If a revised design placed the worker 10 ft from the source, what percent reduction in radiation exposure would there be at the second position relative to the first?
3. Another worker must reach into the instrument in Exercise 1 each day to make a calibration check. In so doing, the worker is exposed to some radiation. If only his hands and forearms are exposed and there are 60 working days per calendar quarter, how much radiation is the worker

allowed to receive per work day in order to reach the allowable limit in a quarter?

4. Visit a facility that uses radioactive material (power plant, laboratory, medical facility, etc.). Discuss with the staff what precautions they take for preparation to use a fissile source, during its use, for its storage, for its transport, and for disposing of used materials. Find out what contingency plans they have in place to deal with a release to the atmosphere or a loss of material by theft or other means.

REVIEW QUESTIONS

1. Name five kinds of radiation and characterize each.
2. Name two natural sources of radiation.
3. Name three products that produce or are sources of radiation.
4. Explain the following units of measure for radiation:
   - **(a)** MeV
   - **(b)** half-life
   - **(c)** rad
   - **(d)** roentgen
   - **(e)** rem
   - **(f)** RBE
5. What factors determine whether a radiation exposure is safe or harmful?
6. What effects may result from high dose rates of radiation?
7. What effects may result from low dose rates of radiation?
8. Which organs are most susceptible to damage from whole body radiation exposure?
9. What is the linearity no-threshold theory?
10. What is a half-value thickness and for what means of control is it used?
11. List eight controls and safeguards that can reduce the exposure to or injury from radiation.
12. Explain how each of the following works in measuring radiation:
    - **(a)** Geiger-Mueller tube
    - **(b)** ionization chamber
    - **(c)** luminescent detectors
    - **(d)** radiation-sensitive photographic film
13. What is radon? Where is it found? How is it controlled?
14. What are the potential benefits of irradiated food?

NOTES

1 www.youtube.com/watch?v=6l5jI4iO4-g

2 E. Marshall, "New A-Bomb Studies after Radiation Estimates," *Science*, 212: 48–51 (1981).

3 21 CFR 1020 (FDA).

4 40 CFR 190 (EPA).

5 49 CFR 172.

6 *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, WASH-1400, U.S. Nuclear Regulatory Commission, U.S. Government Printing Office, Washington, DC, 1975. Available at: www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr75-014/

7 H. W. Lewis, "The Safety of Fission Reactors," *Scientific American*, 242(3): 53–65 (1980).

8 www.cdc.gov/nczved/divisions/dfbmd/diseases/irradiation_food/

9 21 CFR 179; www.fda.gov/Food/ResourcesForYou/Consumers/ucm261680.htm

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CHAPTER 23

NOISE AND VIBRATION

23-1 SOUND AND NOISE

Sound is a characteristic of our environment that provides information and communication. It can offer pleasure from other humans, music, birds, animals, and other parts of nature. It can also create fear and harm.

One of the senses is hearing that involves receiving and interpreting sound. Hearing is an important way to obtain information. Among the human senses, only vision has a higher rate of information transfer. Through hearing we receive critical information, such as the cry of a child or the wail of a siren. We derive information from speech and enjoy the pleasure of music.

Sound is the propagation, transmission, and reception of waves in some medium, most commonly air. Noise is unwanted sound.

23-2 PHYSICS

Terms, Definitions, and Units of Measure

The range of frequencies of greatest interest for safety is the range of frequencies humans can hear. The range of hearing for undamaged young ears is about 16 Hz to 20,000 Hz. Sound waves may have a single frequency (pure tone) or may be a combination of frequencies (a spectrum). White noise is a spectrum with a uniform distribution of energy over a bandwidth.

Most sounds have a complex assembly of frequencies. Frequency analysis or spectral analysis instruments can sort complex sounds into a distribution of frequencies. Noise may be distributed over a wide range of frequencies (broad band) or over a narrow range of frequencies (narrow band). Impulse noise is short duration noise pulses. A pulse can occur once or be repetitive.

The period for one cycle T of a sound wave is the inverse of frequency f:

$$T = l/f \tag{23-1}$$

Wavelength λ is the distance traveled during one period. The speed that sound travels c in air is given by

$$c = \lambda f \tag{23-2}$$

The approximate speed of sound in air at 70 °F is 1130 ft/s. It varies with temperature because temperature affects air density. Another expression for the speed of sound in air is

$$c = 49(T_a + 460)^{1/2} \tag{23-3}$$

where T_a is the temperature of air in degrees Fahrenheit. The speed of sound in water is 4700 ft/s and in many metals it is greater than 16,000 ft/s.

Amplitude is the intensity of sound at a source or at some distance from the source. Units of measure for amplitude are force per unit area, commonly expressed as dynes per square centimeter (dyn/cm^2) and Newtons per square meter (N/m^2).

Sound power describes the energy radiated from a sound source. Sound power has units of watts (W). Sound power level L_P in decibels is the power relative to a value of 10^{-12} W.

Sound pressure refers to a pressure change arriving at some location. The sound pressure level L_p in decibels is the pressure level relative to a value of 2×10^{-5} N/m^2. Sound intensity at some location is the average rate at which sound energy moves through a unit area normal to the direction of propagation. Units for sound intensity are joules per square meter per second (J/m^2/s). Sound intensity level L_I in decibels (dB) is the sound intensity relative to 10^{-12} W/m^2.

Decibels

There is a very wide range of sound pressures encountered in our world. The range extends at least six orders of magnitude. For example, the threshold of hearing is 0.00002 N/m^2 and the threshold for auditory pain is 20 N/m^2. For convenience, a logarithmic scale describes the range of sound measures. Decibels (dB) are dimensionless ratios of a measured value of sound relative to some

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reference value. For sound pressure level L_p, decibels are derived from

$$L_p = 20 \log_{10} p/p_o \quad (23\text{-}4)$$

where

p is the measured root mean square (rms) sound pressure
p_o is the reference sound pressure ($0.00002\ N/m^2$)

Similar expressions represent the decibel units of sound intensity L_I,

$$L_I = 10 \log_{10} I/I_o \quad (23\text{-}5)$$

and sound power level L_W,

$$L_W = 10 \log_{10} W/W_o \quad (23\text{-}6)$$

where

W is the power of a source
W_o is a reference power, commonly 10^{-12} watt

Sound power level may have units of dB or 10^{-12} watts.

Because of logarithmic scaling, sound pressure levels in decibels from two or more sources cannot be added arithmetically to determine the resulting sound pressure level. The data in Table 23-1 helps determine the resulting sound pressure level from two sources. It gives the relationship between the difference in decibels for two sources and the amount to add to the higher of the two sources. If there are more than two sources, add one pair of values at a time and add the third to the result of the first pair. Continue sequentially to account for all sources.

TABLE 23-1 Factors for Combining Two Sound Sources

Procedures:
A. Find the difference in decibels between two sound sources L_1 and L_2 (column 1).
B. Add the number in column 2 corresponding to the difference in column 1 to the highest of the two sources to find the resulting combined sound level L_s.

(1) Difference between two sound sources (dB)	(2) Amount to add to greater sound source (dB)
0.0–0.1	3.0
0.2–0.3	2.9
0.4–0.5	2.8
0.6–0.7	2.7
0.8–0.9	2.6
1.0–1.2	2.5
1.3–1.4	2.4
1.5–1.6	2.3
1.7–1.9	2.2
2.0–2.1	2.1
2.2–2.4	2.0
2.5–2.7	1.9
2.8–3.0	1.8
3.1–3.3	1.7
3.4–3.6	1.6
3.7–4.0	1.5
4.1–4.3	1.4
4.4–4.7	1.3
4.8–5.1	1.2
5.2–5.6	1.1
5.7–6.1	1.0
6.2–6.6	0.9
6.7–7.2	0.8
7.3–7.9	0.7
8.0–8.6	0.6
8.7–9.6	0.5
9.7–10.7	0.4
10.8–12.2	0.3
12.3–14.5	0.2
14.6–19.3	0.1
19.4 or greater	0.0

Frequency

Octaves divide the entire audible frequency range into smaller bandwidths. The highest frequency in an octave has twice the frequency of the lowest frequency and the frequency at the center of each octave designates the bandwidth of interest. The center frequency is the square root of the product of the lowest and highest frequency. The center frequency of an octave above and adjacent to one of interest is twice the center frequency of the octave of interest. Center frequencies of some standard octaves are 125, 250, 500 and 1000.

Sound Distribution

Sound pressure decreases inversely with distance from a source. In a free field, sound moves from a source in a spherical pattern. However, most sources and environments are not free fields, so sound may project unevenly. It may strike objects, panels, walls, and ceilings and be reflected. It may become trapped and absorbed in holes in materials and lose energy. It may reflect and create standing waves that oscillate in place. It may travel through panels and objects. It will travel around objects and through openings. Sound may cause the mass of a panel to move and transmit pressure waves on the opposite side of the panel.

It is very difficult to predict the sound incident at some location in an actual field. It is easier to measure the actual sound pressure level at a specific location.

Surface Absorption

One can predict sound absorption by surfaces. The unit of measure for sound absorption is sabin. One sabin is the

absorption by 1 square foot of a perfectly absorptive surface. The possible noise reduction, *NR*, from absorption measured in sabins is

$$NR = \log_{10} \frac{\text{absorption before treatment}}{\text{absorption after treatment}} \qquad (23\text{-}7)$$

Sound Transmission Across Barriers

When sound reaches a surface, the surface absorbs some of the energy. Some passes through the surface to the other side. When designing walls and other sound barriers, a focus is on the reduction or sound transmission loss, *TL*. Sound transmission loss is the reduction in sound energy across a barrier

$$TL = \log_{10} \frac{\text{acoustic energy transmitted}}{\text{incident acoustic energy}} \qquad (23\text{-}8)$$

23-3 HEARING

Anatomy and Physiology of the Ear

The ear is a fantastic instrument and it is quite complex. A basic knowledge of its anatomy and physiology is essential to understanding the hazards of noise and selecting and applying noise hazard controls.

As illustrated in Figure 23-1, there are three main segments of the ear: the external, middle, and inner ear. The external ear is the part we see. The main portion is the pinna. It is cartilage covered by skin that helps focus sound toward the ear canal, the external auditory meatus. The external ear amplifies the arriving sound by as much as 23 dB. At the inner end of the external ear is the ear canal. It ends at the tympanic membrane or eardrum. Arriving sound waves transfer sound energy to motion of the eardrum.

The middle ear begins on the inner side of the ear drum. The middle ear is an air-filled chamber that vents to the throat through the Eustachian tube. It contains three small bones (ossicles) and two suspensory muscles for them. The three bones are the maleus (hammer), the incus (anvil), and the stapes (stirrup). Sound energy travels across the three bones from the tympanic membrane of the outer ear to the oval window of the inner ear. The action of these three bones produces an amplification of about 2.5 dB. The suspensory muscles are the tensor tympani and the stapedius. When there is a loud sound, these muscles contract and provide some attenuation of energy transmitted across the three bones.

The main element for hearing is the cochlea or inner ear. It is a fluid-filled coil that has two chambers over its length divided by thin tissue. Sound energy travels from the oval window or base of the cochlea to the distant end or apex of the coil. The waves travel through one chamber and reflect back through the second chamber to the round window, which deflects to adjust for the pressure from the waves. The round window and oval window both separate the inner ear from the middle ear.

Figure 23-2 shows a cross-section of the cochlea. There is actually a third chamber extending along the length of the coil that contains the sound receptor mechanisms. The membrane separating this third chamber from the first is

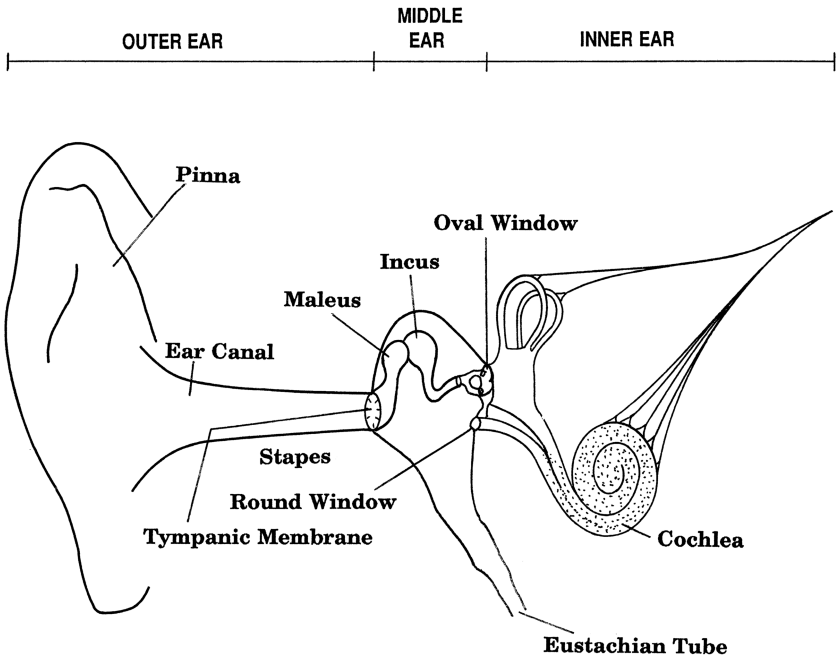


Figure 23-1. Major anatomical features of the ear.

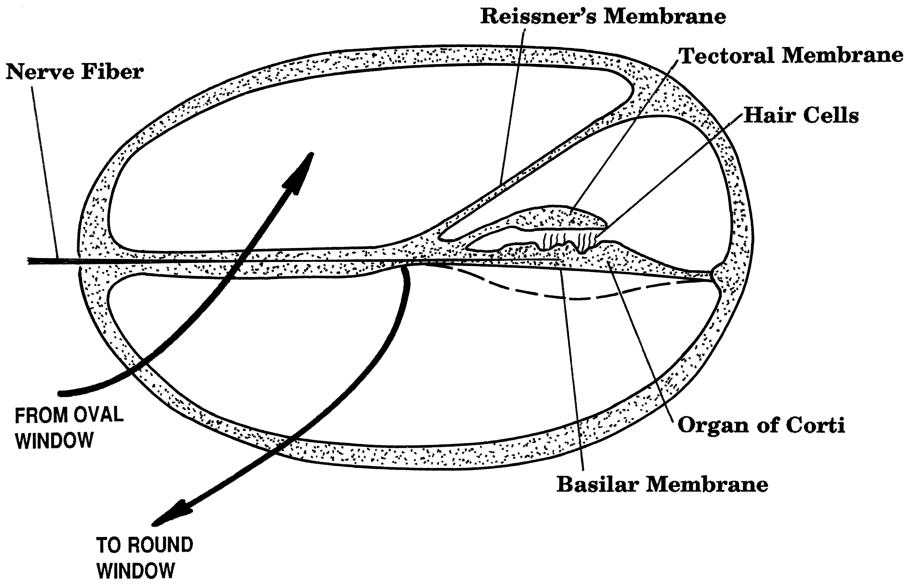


Figure 23-2. Cross section of the cochlea.

Reissner's membrane. The membrane separating this chamber from the second is the basilar membrane. Located along the basilar membrane is the Organ of Corti. It contains rows of hair cells and a layer of tissue, called the tectoral membrane. It rests on the ends of the receptor hairs. The rows of receptors have two groups: inner hair cells and outer hair cells.

When sound travels along the chambers of the cochlea, the membranes enclosing this third chamber deflect. The deflection converts movement of the tectoral membrane against the inner hair cells into nerve impulses by the receptor hair cells. In general, the hair cells at the base of the cochlea sense high frequencies. Those near the apex sense low frequencies. Recent theories suggest that the inner hair cells are the receptors, whereas the outer hair cells serve an amplification function. In hearing loss, damage to the outer cells is more prevalent than to the inner hair cells.

Audition and Audiology

The primary means for hearing is sound traveling through the outer and middle ear to the inner ear. A small amount of hearing occurs through bone conduction to the inner ear.

The ear does not convert physical sound arriving at the ear directly to equivalent perceived sound. The ear is not equally sensitive to tones of equal sound pressure. As a result, there is a scale called loudness. Loudness is the perceived amplitude of sound. Studies have produced equal loudness curves for pure tones. In general, the ear is most sensitive at frequencies toward the middle of the auditory range.

Audiology is the assessment of hearing ability. Typically, a subject sits in a room that has a very low sound level. The room is free of external sound sources. The subject wears earphones connected to sound equipment called an audiometer. The operator sends a sequence of pure tones from the equipment to the subject and increases the amplitude of the tone until the subject responds. Subjects use hand gestures or a response switch to indicate they hear a tone. Indicators on the operator's equipment show the tone and level. The hearing threshold is the minimum level heard. The hearing threshold varies among subjects and by frequency. The procedure continues through a range of standard octave band center frequencies. The operator notes the responses of the subject. The operator then compares the responses to a standard. A plot of results is an audiogram. It notes the reduction in hearing threshold level at each octave band. The chart shows negative decibels relative to the reference standards.

23-4 HAZARDS OF NOISE

There are many effects of noise on people. Most effects are detrimental. The best-known effect of noise is noise-induced hearing loss. There are many other effects that contribute to accidents and health problems.

Types of Hearing Loss

There are several causes for hearing loss. Some are due to disease, such as infections of the middle ear and scar tissue formation on the eardrum. Common infectious diseases encountered around the world often lead to hearing loss. Vaccinations have reduced many of these results. Some hearing loss stems from trauma. Trauma for the ear may be perforation of the eardrum or separation of the ossicles of

CASE 23-1

Most everyone know someone who has significant hearing loss and wears hearing aids to provide assistance with their problem. Here are some famous people who had hearing loss.

- **Helen Keller** was both deaf and blind from an infectious disease in childhood.
- Many famous musicians have noise-induced hearing loss from a long history of noise exposure. Two with hearing loss are **Ozzy Osborne** (Black Sabbath) and **Pete Townshend** (The Who).
- **William Shatner** has a history of tinnitus that resulted from a prop explosion on the set of *Star Trek* where he played Captain Kirk.
- During their tour in the White House, two presidents had hearing aids fitted because of high frequency hearing loss: **Bill Clinton and Ronald Reagan**.
- **Ludwig van Beethoven** experienced the start of hearing loss at age 26. It progressed quite rapidly. The exact cause is not known. He continued composing with progressively less hearing. At the premier of his Ninth Symphony, he could not hear the audience's applause.

the middle ear. Conductive hearing losses involve the outer and middle ear. Sensory losses involve the Organ of Corti and sensory nerves. Hearing loss can also occur in the brain. Most often brain-related losses involve difficulties in interpreting sound and speech. Some hearing impairments are psychological with no physiological basis.

Noise-Induced Hearing Loss

The greatest safety concern is noise-induced hearing loss. Exposure to noise can produce hearing loss. Both duration of exposure and sound intensity can lead to hearing loss. High frequency noise is more damaging than low frequency noise. Continual noise is more damaging than intermittent noise.

There are individual differences among people for noise exposure. A noise exposure for one person may not produce the same loss experienced by another person. However, the relationship between noise exposure and hearing loss is clear.

Temporary Threshold Shift One type of noise-induced hearing loss is a temporary threshold shift (TTS). Exposure to excessive noise will elevate the hearing threshold. Excessive noise damages the Organ of Corti and its receptor hair cells. Relatively short exposures to loud noise can produce TTS. For example, listening to a loud musical group or recording for an hour or two can create TTS. This disability is temporary. After some recovery period, hearing sensitivity returns to pre-exposure levels.

Permanent Threshold Shift Continued exposures to noise that produce TTS will cause a permanent decrease in hearing sensitivity and elevate the hearing threshold. Long-term exposure produces permanent threshold shift (PTS). Hearing sensitivity does not return after a recovery period. The sensory damage to the Organ of Corti becomes permanent. There are many examples of hearing loss among riveters in factories, airplane pilots, and tractor-driving farmers. Some of these hearing losses have colloquial names, such as aviator's ear or farmer's ear.

Acoustic Trauma Loud noise from explosions, artillery guns or cannons or from similar sources of pressure waves may rupture the eardrum or damage the structure of the middle or inner ear. Such conductive damage has the name acoustic trauma. In some cases there is temporary damage. The injured tissue may heal, restoring hearing to full or near-full sensitivity. In other cases, the physical injury will produce permanent hearing loss.

Other Effects of Noise

Communication Effects Noise can interfere with audio warnings intended to prevent accidents. For example, a person may not hear the horn of a car or train in a noisy environment. Noise may interfere with cries for help and prevent rescue attempts.

Noise can also interfere with speech communication. One worker may not understand or may misunderstand what another says. A loss in the high frequency range will reduce hearing of some soft speech sounds, like s, sh, and th. The hearing loss may cause failure to hear certain words or create speech misinterpretations.

One index for assessing the ability to communicate verbally is the Preferred-Octave Speech Interference Level (PSIL). PSIL is the numerical average sound level (decibels) measured for each of three octave bands (500, 1000, and 2000 Hz). A study of the relationship between PSIL and speech intelligibility in different ambient noise conditions

CASE 23-2

Two people were operating an injection machine. They relied on verbal communication in a noisy workplace to manage the machine's operation. There was only one set of controls. One worker handled the controls. A second worker removed completed parts. Material to make a part fed directly from a hopper of polyethylene pellets at the right part of the machine's cycle.

The worker handling the controls heard the verbal command of the second worker. The first worker thought the second worker said: "Go ahead," the normal report after each cycle. However, the second worker actually said: "Don't go ahead." The second worker reached into the danger zone to clear a part that did not release the way it was supposed to. The first worker tripped the controls that caused the die to close. The die closed on the second worker's hand.

Chapter 13 discussed some ways to prevent this kind of accident. Chapter 33 will address other considerations of communications.

helps estimate potential communication problems (see Figure 23-3).

Reduced Learning Studies show that noise in classrooms and homes may hinder language skill development in children. Not only is attention interrupted, but speech and particular speech sounds are not communicated well.

Startle Response A sudden noise will cause a startle response in people. The reaction is involuntary. Characteristics are vasoconstriction, an increase in blood pressure, dilation of pupils, and muscle contraction. Every time a loud noise occurs, these reactions occur. After a few minutes of the loud noise, conditions return to normal. The startle reaction may create errors in critical situations.

Physiological Reactions People do not become accustomed to noise. Studies of people who work in noisy environments suggest they have higher incidence of circulatory problems, heart disease, ulcers and medical problems in general. Blood pressure is higher in children exposed to aircraft noise in schools. Some studies link noise levels during pregnancy to low infant birth weights. Many of these effects occur at noise levels below those necessary for

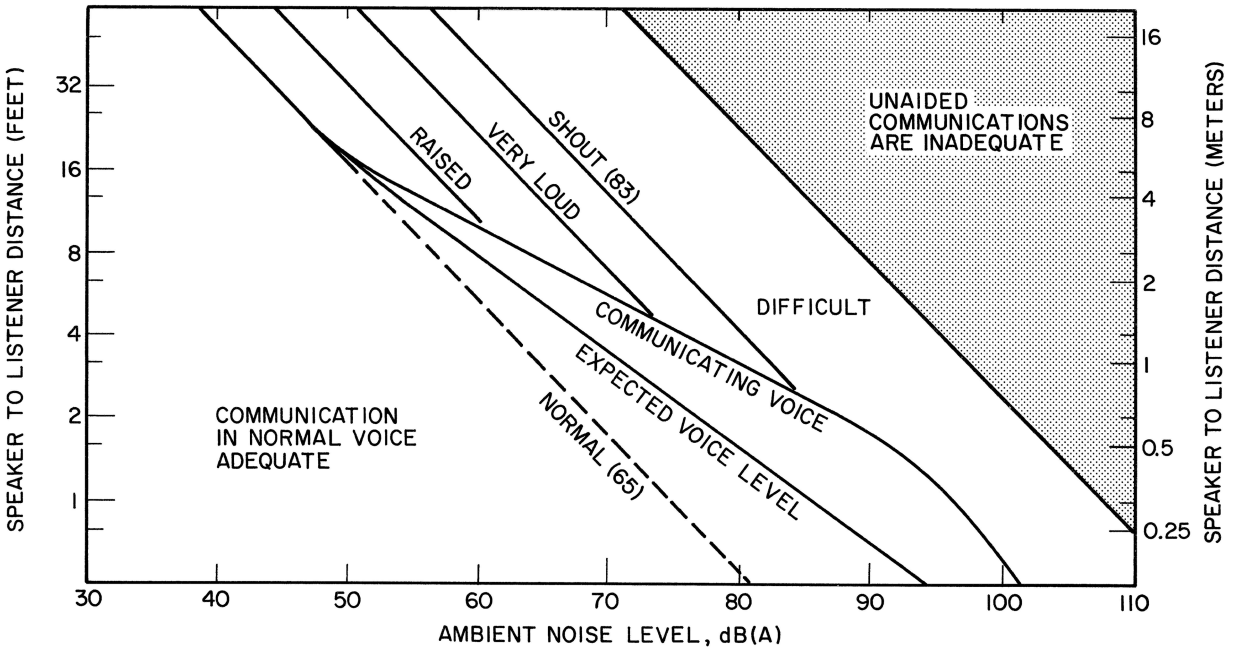


Figure 23-3. Permissible distance between a speaker and listeners for specified voice levels and ambient noise levels. The levels in parentheses refer to voice levels measured 1 m from the mouth. (From MIL-STD-1472G.)

hearing loss. Exposures to very high noise levels can produce vertigo and nausea.

Sleep Disruption Noise can prevent someone from falling asleep. It can rouse one from sleep to lighter levels of sleep or wakefulness. Disruption of sleep may affect performance during daily activities.

Social Effects Noise affects social behavior. Interference with communication can raise frustration levels and impact relationships. Noise can distract attention away from critical activities. Noise can lead to headache, irritability with others (including parents/children and workers/supervisors), anger, and fatigue. On occasion, it can lead to extreme behavior. Noise may be annoying. Annoyance is subjective and, in part, a function of noise content. What may be meaningful or pleasant to one person may be annoying to others because of intensity or content. Time and place can affect annoyance. People become irritated by noise when relaxing or trying to sleep.

23-5 STANDARDS

Origin of Exposure Standards

Exposure standards for noise began in the 1950s when people recognized that extended exposures caused hearing loss. The U.S. Air Force issued the first standard in 1956. Standards committees and others struggled to develop consensus on exposures. In 1969, the American Conference of Governmental Industrial Hygienists (ACGIH) offered recommendations. That same year the Walsh-Healey Public Contracts Act incorporated those initial threshold limit values. After Congress created OSHA in 1970, the agency accepted the same exposure standards. In 1971, the Federal Coal Mine Health and Safety Act also created a standard on noise exposure. In 1981, OSHA began requiring hearing conservation programs by employers for certain noise environments.

OSHA Standards

Table 23-2 lists the OSHA permissible exposures.[1] They consider noise levels that produce hearing loss through exposures of an 8 h workday. The standards also include a maximum for impact noise. When exposures vary during the workday, a computed time-weighted average noise (TWAN) helps determine if the exposures in Table 23-2 are exceeded:

$$\text{TWAN} = C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n \qquad (23\text{-}9)$$

where

C_x is the total time of exposure at a specified noise level
T_x is the total time of exposure permitted at the specified noise level

TABLE 23-2 OSHA Permissible Noise Exposures[a]

Duration of Exposure (hr)	Sound Level (DBA slow response)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115
Impulse or impact noise	140 peak sound pressure level

[a]29 CFR 1910.95 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9735. Refer to the full standard for additional details.

If the value of TWAN is greater than 1.0, the exposure exceeds the OSHA limits.

Example 23-1 A noise exposure for a worker is the following:

Noise Level (dBA[2])	Duration (hr)
110	0.25
100	0.5
90	1.5

Is the OSHA criteria exceeded for the work shift?

Using information from Table 23-2 and applying Equation (23-9),

$$\text{TWAN} = 0.25/0.5 + 0.5/2 + 1.5/8 = 0.938$$

Because 0.938 is less than 1.0, the exposure fall just below the allowable limit of 1.0.

OSHA considers continuous noise as that involving noise level maxima that occur at intervals of 1 s or less.

Other Standards

Workplace Compared to OSHA exposure standards, the Threshold Limit Values® of ACGIH[3] for noise exposures limit exposures to significantly lower sound levels.

For the European Union, Directive 2003/10/EC addresses noise exposures.[4] The Directive focuses on risk and risk reduction. It leaves exposure standard to each member country. The majority of countries set 85 dB as the level for allowable 8-hour exposures. A few countries have higher exposure limits, up to 90 dB. Many countries also have standards for exposures at which health surveillance and hearing testing must occur and for which employers must issue hearing protection.

Public Exposures Public exposures to noise come from traffic, industry, recreation, construction, airports, and other sources. The noise sources create a variety of public issues as discussed in Section 23-4. The U.S. EPA identified the noise levels that impact public health and welfare, but left setting standards and enforcement of public noise to state and local governments.[5] In the U.S. there are hundreds of state and local laws and ordinances on noise.

Similarly, the European Union set a directive addressing assessment and management of environmental noise.[6] It does not include recommended exposure standards, which the directive leaves to each country.

23-6 CONTROLS

There are many controls for noise. One approach groups engineering controls into four classes:

1. Avoid noise sources before they become introduced into an environment.
2. If noise sources exist, replace equipment, processes or materials with quieter ones.
3. If replacement of noise sources is impossible, modify elements to reduce emitted noise.
4. Modify sound and its environment.

Another way to classify noise controls is:

1. Treat the source.
2. Treat the path.
3. Treat the receiver.

Treating the source includes the first three options in the first classification scheme. Treating the path is the same as the fourth option. Controlling noise at the receiver often involves an enclosure for people or providing personal protection equipment, both of which limit sound reaching people from outside sources.

Administrative controls for noise are part of treating the receiver. An additional element for this strategy includes notifying people about noise levels and necessary protection. There is a need to monitor workers for hearing loss when environments are noisy and near recognized noise exposure limits. Among administrative controls, managers must help ensure that workers actually wear assigned hearing protection in noisy environments and that engineering controls are in place and working properly. Administrative control involves regular surveillance of noisy environments.

Often a combination of controls is necessary. Some solutions have physical limits. Others have economic limits or require cooperation of individuals and work groups.

Avoid Noise Sources

One way to control noise problems is to analyze processes and equipment during planning and design in order to prevent noise problems from occurring at all. For example, set noise specification limits for purchased equipment and make sure equipment orders include such specifications. Watch for high velocity flow, high speed equipment and high pressure processes, which often create significant noise levels. Establish noise specifications for potential sources. Analyze processes and systems to reduce noise generation. Often it is cheaper to design facilities and buy equipment with noise control than to try to control noise sources later.

Look for noisy locations in a floor plan or plant layout. Look for ways to enclose potentially noisy activities, processes, and equipment to prevent noise from traveling to less noisy areas. Group noise sources to lower costs for controls. Try to separate people from noise sources by distance and barriers. Look for and avoid routes or channels by which sound can travel from one location to another.

Analysis of sound travel will help when planning noise control in a room. Noise travels away from a source. The energy level in a sound field will decay with the square of the distance from a source. However, most rooms have reflective surfaces, such as floors, walls, and ceilings. Placement of noise sources in a layout can help with noise control. For example, placement of noise sources in a corner near highly reflective floor, ceiling and walls will concentrate noise energy in one location and one direction. Conversely, placement of noise sources away from reflective surfaces may give noise a chance to dissipate to an acceptable level.

Room design may incorporate sound absorption. A room constant, R, is a measure of the ability of a room to absorb sound. A high room constant will have a high level of sound absorption. A computed room constant is

$$R = \frac{\alpha_m S_t}{1 - \alpha_m} \tag{23-10}$$

where

α_m = mean sound absorption coefficient for all room surfaces (dimensionless)

S_t = total area of room boundary surfaces (square feet)

and

$$\alpha_m = \frac{S_1\alpha_1 + S_2\alpha_2 + \ldots + S_n\alpha_n}{S_1 + S_2 + \ldots + S_n} \tag{23-11}$$

where subscripts refer to particular surfaces that make up the total surface and their respective absorption coefficients.

During the design phase, one can specify and select sound-absorbing surface finishes for ceilings, walls and floors. This will help reduce sound to acceptable levels. However, there is a limit to the benefit from absorbing surfaces. Also note that absorbing surfaces only reduce

CASE 23-3

A manufacturer had a production line in which machines filled boxes with product and sealed the boxes. The filled boxes moved to the packing and shipping area for final actions.

Just beyond the fill and seal activities, the company installed an air stream under the line. The air flow created just enough force to flip any partially filled boxes off the line. The air stream came from a small diameter pipe and created a high frequency noise source.

In order to reduce the noise hazard, the company changed the pipe to a larger diameter. The change created a low speed air flow covering a larger portion of the bottom of a filled box. The force created by the modified air stream was the same as the high speed, narrow stream. The modified design eliminated the noise and proved as effective at removing underfilled boxes from the production line.

the sound coming from the source and do nothing to change the source.

One can also analyze the effect of distance of people from sound sources. Keeping people away from sources can lessen potential violations of exposures standards and adverse effects.

Some materials, processes, and equipment have components that transmit sound or have natural frequencies that can amplify sounds. Metal panels, pipes, and tubes often vibrate and ring. The flow of high pressure and high velocity liquids and gases often produces higher noise levels than those with low pressures and velocities. One should look for these potential noise sources and seek to reduce them during design of processes, buildings, and equipment.

Replace Noise Sources

If there are noise sources, a design goal is seeking to substitute alternate equipment, materials, processes, and activities that will reduce noise. Many of the actions suggested for design and planning apply here. Cost is often the main difference. Usually it is cheaper to prevent noise sources than to fix them after they are in place.

Modify Noise Sources

There are many options for modifying a sound source. Analysis of a sound source will determine which options are feasible, practical, and economical. Because many control options are frequency dependent, one must conduct a noise survey of an environment and the sources within it to help define the problem and potential solutions. Normally, noise survey data will give records of total sound level and sound levels for each octave band.

Control Direction of Source One option is to direct the sound from a source away from potential people locations. For example, one can direct an opening in a machine (vent, duct, material feed opening, etc.) away from operators or extend a vent or duct through a roof or wall. One can place noise sources where they do not reflect noise to a large area.

Reduce Flow Rates High speed and high pressure gases and liquids passing through pipes and ducts often create high sound levels. This is particularly true for flow through valves, bends, and other transitions where fluid turbulence is high. Reducing pressures and speeds can reduce sound sources. One can avoid transitions in flow lines and turbulence that produce noise. One can also place transitions in locations away from people.

Reduce Driving Forces Some equipment produces oscillations and vibrations. The greater movements may create noise sources in the equipment or items attached to the equipment. It is possible to reduce forces creating sound by reducing the forces producing oscillations and vibrations. For example, reducing shaft speed and balancing rotating equipment will reduce forces and eccentricity in rotating shafts.

Similarly, separating vibrating sources from sheet metal and other panels will prevent the large areas from creating sound waves. There are several ways to create the isolation. One way is to use flexible coupling and flexible connections. The couplings and connections prevent vibration of one element from transmitting force to another element that would be a noise source. For example, placing motors and vibrating equipment on independent footings prevents the transmission of vibration to other elements. Another example is connecting air handlers (fan units) to ductwork with fabric connections instead of using standard metal connections. One can place various kinds of isolation pads between motors or machines and the structures on which they rest. An appropriate isolation pad prevents transfer of vibrations from machines to the structures. Manufacturers of isolating materials, pads, and other devices usually have recommendations for selecting the appropriated products. They have test data to show the effectiveness of their isolating products at various frequencies and forces.

Control Vibrating Surfaces Panels and other elements of equipment and buildings often vibrate perpendicular to their surface. That creates large pressure waves. There are ways to reduce the amplitude of such vibrations. One method is to reduce the size of a vibrating panel. Another method is to add damping material, bracing, or stiffness that reduces panel motion. Another method is to add mass. If the source frequency is the same or nearly the same as a panel, changing one will help reduce vibration. If the natural frequency of a panel is the same as a source frequency, one of them needs to change.

One example illustrates a simple solution. When heating and cooling technicians create a section of a duct for handling conditioned air, it is common to place an X crease on the large panel sections. The crease stiffens the flat side of a large duct and prevents vibration from occurring.

In constructions of frame and drywall wall panels, it is possible to prevent sound from transferring across a wall panel. One method involves mounting a resilient metal strip on the wood or metal studs and attaching drywall panels to the strips instead of to the studs. That prevents sound waves on one side of a wall causing the panels on the other side of the wall section to create sound waves. Drywall manufacturers offer design information on proper installation and effectiveness of resilient strips at various frequencies.

For some equipment with large surfaces or panels, a method for reducing sound waves involves making a sandwich panel. First, someone sprays the surface or panel with a stiffening agent that will help reduce panel vibration. Then, adding a second layer will form the sandwich. This combination stiffens the panels and reduces creation of sound waves.

Using heavier gauge panel material can increase panel stiffness. The heavier material will require greater forces to produce displacement and sound waves. The increase in panel mass is a primary factor.

Some machines have drums that rotate. After creating stamped metal parts in presses, the parts often go into a drum that rotates. Some call the machine a tumbler. Someone then adds small pellets, called shot. When the shot and parts tumble in the drum, the shot removes burrs and smooths the surfaces of the parts. These tumblers are noisy. However, covering the outside of the drum with foam and lining the inside with resilient rubber materials will reduce the noise generated.

Some large rooms convert to several smaller rooms with folding partitions. Some partitions are plastic. By itself, the plastic partitions do little to stop sound transmission. Most manufacturers incorporate lead strips into the sections that fold. The goal is to add mass to the partitions to reduce the amplitude of panel vibration and reduce sound transmission. Companies selling partitioning panels provide sound attenuation data for their products.

One method for reducing the range of frequencies transmitted across panel walls is to divide a panel into small elements. Small sections change the frequencies transmitted. If the small panels add mass, that can also lower sound transmission.

Modify Sound Paths

There are several ways to modify the path sound waves may take. There are enclosures, room absorption, barriers or shields, absorption along a transmission path, and mufflers. Not all methods are available to reduce noise for each design problem.

Enclosures The ideal enclosure is a full enclosure with no openings that fully encloses a sound source and prevents it from carrying into a larger environment. In most cases, it is not possible to achieve a full enclosure. For machine functions, there is often a need for an opening through which materials feed the point of operation or from which parts exit. There may be openings for lubricating and servicing equipment. Some openings may be temporary, such as a door or hatch. Even if there are small openings or cracks in an enclosure, significant levels of sound can escape.

Inside an enclosure, reverberating sound can build up to higher sound levels. One way to reduce reverberating buildup is to add sound-absorbing materials inside an enclosure. An average absorption coefficient inside an enclosure of at least 0.7 will make buildup insignificant.

An expression for sound pressure level L_p inside an enclosure is

$$L_p = L_w + 10\log_{10}(Q/4\mathrm{r}^2 + 4/R) + 10.5\ \mathrm{dB} \qquad (23\text{-}12)$$

where

L_w is the sound power level of the source relative to a reference value of 10^{-12} W
Q is the directivity factor
r is the distance from the acoustic center of the source (feet)
R is the room constant (square feet)

Equation (23-12) helps in developing the most effective and economical enclosure. In addition, Equations (23-10) and (23-11) help in evaluating several possible conditions. For each set of conditions and possible materials, the computations will help identify the transmission loss required and noise reduction achieved.

Consider an example procedure. First, evaluate initial, unenclosed conditions for some predetermined distance from the sound source. Assume the difference between L_p and L_w is D_u. Second, evaluate the enclosed sound source and compute a new difference D_e between L_p and L_w. This value indicates the enclosure causes an increase in L_p due to reverberant buildup. The difference between the enclosed condition and the unenclosed condition, $D_e - D_u$, is the transmission loss required because of the enclosure, TL_e.

TABLE 23-3 Sound Transmission Loss in Decibels of Various Materials

Octave Band Center Frequency (Hz)						
Material	125	250	500	1000	2000	4000
Door, heavy wooden, special hardware, rubber gasket all around edge, 2 ½ in. thick	30	30	24	26	37	36
Door, solid oak, ordinary hung, 1 3/4 in. thick	12	15	20	22	16	–
Glass, 1/4 in.	27	31	33	34	34	42
Sheet steel, 1/4 in.	23	38	41	46	43	48
Sheet lead, 1/16 in.	32	33	32	32	32	–
Gypsum wall board, ½ in.	18	22	26	29	27	26
Wall: ½ in. gypsum wallboard on both sides of 2 × 4 studs 16 in. O.C.	20	27	37	43	48	43
Concrete, reinforced, 4 in. thick	37	36	45	52	60	67
Concrete block, 4 in. hollow, dense aggregate, no surface treatment	30	39	43	47	54	50
Concrete block, 8 in. hollow, dense aggregate, no surface treatment	40	53	54	58	58	50

The actual decibel level for the unenclosed condition may be above some desired sound level based on a standard. Call this difference TL_s. It is common to adjust TL_s upward by about 5 dB to ensure that the final solution is effective. The total transmission loss TL_t the enclosure must achieve is $TL_s + TL_e$. Then select and analyze enclosure materials and sound-absorbing lining materials to determine the design that is most cost-effective. Repeat this procedure for each octave band center frequency.

Controlling sound transmission through the enclosure materials is another important consideration. One can select materials that effectively limit sound transmission. Table 23-3 lists some sample materials and sound transmission properties, assuming well-sealed enclosures.

The sound transmitted through an incomplete enclosure is largely a function of the unenclosed portion of the full enclosure, whether from cracks or other openings. Curves shown in Figure 23-4 give estimates of sound reduction. Enter the chart at the bottom using data on the maximum transmission loss for a full enclosure. Move vertically to intersect with a curve representing the opening (percent of full enclosure). Then read the actual reduction along the left of the chart.

Room Absorption One can place sound-absorbing materials on the surfaces of a room or surfaces of objects within it to reduce sound levels. That replaces hard, smooth reflecting surfaces with porous, sound energy-absorbing materials. There is a practical limit to this approach. To a great extent, the effectiveness of additional treatment depends on the lack of sound-absorbing surfaces prior to treatment. The noise reduction is computed as

$$\mathrm{NR} = 10 \log A_2 / A_1 \qquad (23\text{-}13)$$

where

A_2 is the total absorption units (sabins) in a room after treatment

A_1 is the total absorption units (sabins) in a room before treatment

Total absorption units A_x are the sum of products of various surface areas involved times the absorption coefficients α_x at specific frequencies for the respective surfaces.

The absorption properties of room finish materials vary with frequency. Manufacturers of sound-absorbing materials usually have data on absorption coefficients listed by bandwidth center frequencies. Table 23-4 gives sound absorption coefficients for selected building materials. The sound absorption for a clothed person in a room varies with frequency and is about 3–5 sabins.

Barriers or Shields Another approach to reduce sound transmission along a path is to insert a barrier, often some type of panel. The purpose of a barrier is to deflect sound waves that would otherwise move between a source and a receiver. A barrier extends from the floor to some height below a ceiling. Figure 23-5 illustrates the concept. Geometry of the configuration and sound properties of the surfaces involved all affect a panel's effectiveness. The effective height is H_e. The greater the angle θ created by the shield, the more effective the shield. The smaller the ceiling angle λ produced by a reflection of the sound at the ceiling, the lower the shield effectiveness. The greater the ceiling angle λ, the more sound energy a porous ceiling surface can absorb. The sound absorption of the panel surface, the sound transmission through the shield itself, and the absorption of the ceiling surface all contribute to the effectiveness of a shield.

Modular office furniture often places one employee on the opposite side of a partition from another employee. The partitions and paneling usually have sound-absorbing surfaces that help reduce noise in the workspaces. When considering sound control with such panels, which are barriers or shields, the greatest transfer of sound between workstations is a vertical reflection. Sound from one side of a panel goes nearly straight up, strikes a ceiling and reflects down to the other side. Barriers and shields do little to prevent such reflective noise movement.

A possible solution for barriers and shields is to place a small panel across the top of the shield or barrier at an angle perpendicular to the sound source to stop the vertical movement of sound. Another solution is to apply sound-absorbing material to the ceiling to reduce sound reflected downward.

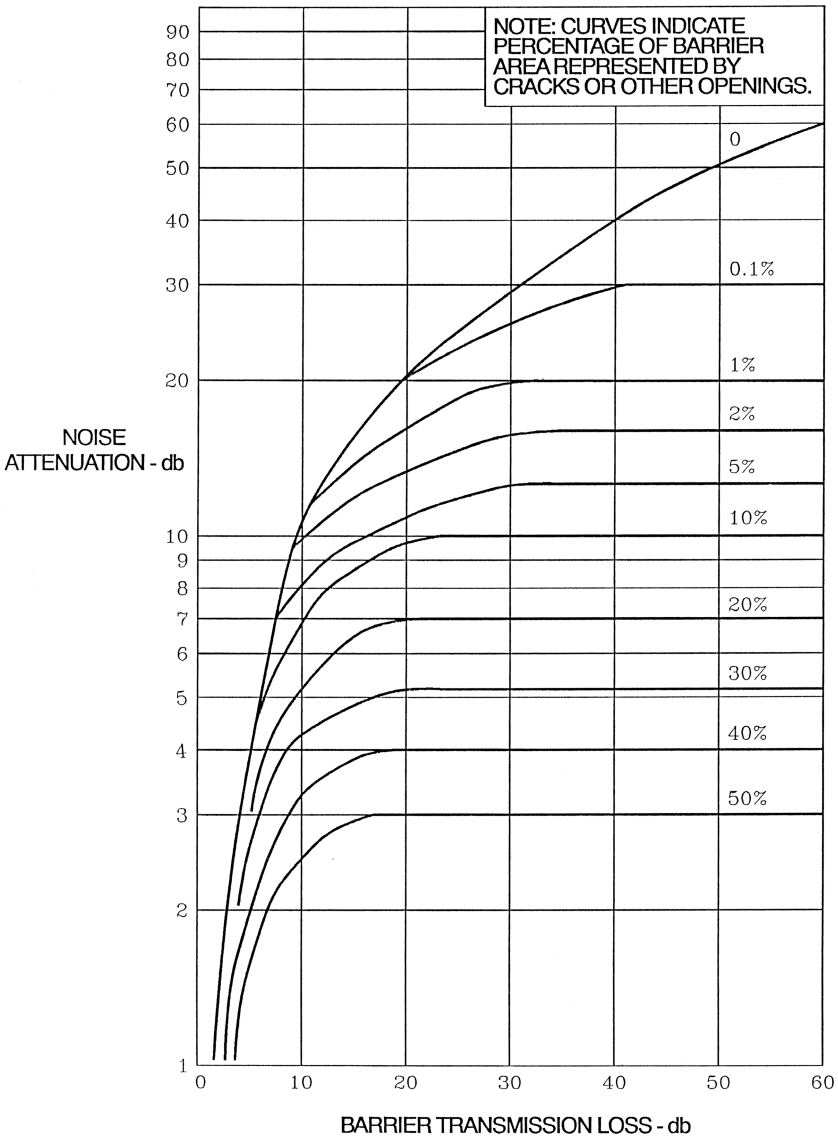


Figure 23-4. Effect of enclosure leaks on barrier sound transmission loss (TL). Enter the chart with the barrier transmission loss for a fully enclosed noise source. Move vertically to intersect with the curve representing the percentage of the barrier area presented by cracks or openings. From the intersection, move left to read the noise attenuation actually achieved.

Absorption Along a Transmission Path In many buildings there are paths between one location and another through which sound can travel. Typical paths are heating and ventilation ducts. Ducts lined with sound-absorbing material can reduce the amount of sound transmitted. The noise reduction (NR) is a function of the absorption properties of the lining material, the length of duct and the cross-section of the duct. NR has units of dB reduction per foot of duct length:

$$NR = \frac{12.6\,P\alpha^{1.4}}{A} \qquad (23\text{-}14)$$

where

P is the perimeter of the duct in inches
α is the absorption coefficient of the lining material at a particular frequency
A is the cross-sectional area of the duct in square inches

Mufflers Mufflers reduce the sound along a path and reduce the sound created by flow of a fluid. There are several ways to design them. The preferred approach depends on physical dimensions, design goals, and other factors.

One type of muffler is a straight-through, dissipative muffler (see Figure 23-6(a)) that creates very little pressure drop. Material placed around the outside of the pipe and

TABLE 23-4 Sound Adsorption Coefficients for Selected Building Materials

Octave Band Center Frequency (Hz)						
Material	125	250	500	1000	2000	4000
Brick, unglazed	0.03	0.03	0.03	0.04	0.05	0.07
Carpet, 1/8 in. pile	0.05	0.05	0.10	0.20	0.30	0.40
Carpet, 1/4 in. pile	0.05	0.10	0.15	0.30	0.50	0.55
Floor, concrete	0.01	0.01	0.01	0.02	0.02	0.02
Floor, wood	0.15	0.11	0.10	0.07	0.06	0.07
Glass fiber, 1 in. thick (3 lb/ft3, mounted with impervious backing)	0.14	0.55	0.67	0.97	0.90	0.85
Glass fiber, 3 in. thick (3 lb/ft3, mounted with impervious backing)	0.43	0.91	0.99	0.98	0.95	0.93
Gypsum board, ½ in. nailed to 2 × 4 studs, 16 in. O.D., painted	0.10	0.08	0.05	0.03	0.03	0.03
Paneling, hardwood, 1/4 in. on wood framing	0.58	0.22	0.07	0.04	0.03	0.07
Fabric, light velour, 10 oz/yd2, hung straight in contact with wall	0.03	0.04	0.11	0.17	0.24	0.35
Fabric, heavy velour, 18 oz/yd2, draped to half area	0.14	0.35	0.55	0.72	0.70	0.65

perforations in the pipe wall produce sound absorption. The sound-absorbing material may have an outer shell. This type of design is most effective for pipes with less than a 6 in. diameter.

A second type of muffler is a dissipative muffler with a center core (not shown). This type is effective for pipe diameters greater than 6 in. Channels inside the muffler distribute the gas flowing through the muffler. Perforations in the channel walls allow surrounding absorptive material to reduce sound energy. The channels have internal and external absorbing material that creates larger areas for sound absorption.

A third type of muffler is a reactive type [see Figure 23-6(b)] that uses baffles and resonance phenomena to reduce noise levels. Resonance mufflers are effective for narrow band frequencies because of design limitations.

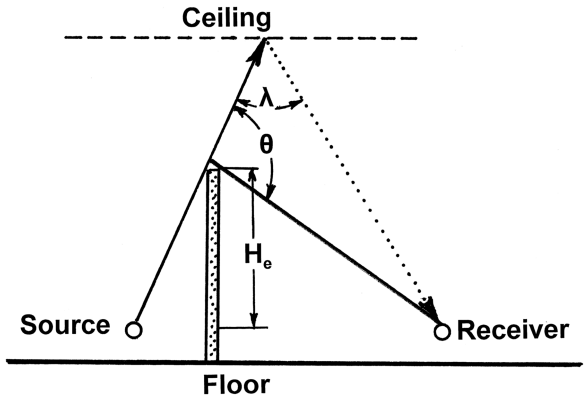


Figure 23-5. A noise shield can reduce the sound level between a noise source and a receiver. Effectiveness improves as the angle θ gets smaller. A reflective ceiling can reduce the effectiveness of a shield, especially if the reflective angle λ is small, nearly perpendicular to the source and receiver. When λ is large, a ceiling with sound absorptive surface properties can reduce the ceiling reflection.

Treat the Receiver

A temporary means for controlling noise at the receiver is the use of earplugs and earmuffs. Chapter 28 discusses personal protective equipment.

A permanent means of controlling noise exposure is a partial or full enclosure. Enclosed work spaces are much like enclosed sound sources. The enclosing walls must minimize sound transmission. Place openings in enclosures on sides away from sound sources to reduce the chance of sound penetrating them or the cracks along their edges. Doors or windows must include seals of cracks around their edges. The intersections of ceilings and walls or walls and floors must have sealed joints. Sealing cracks is essential, since significant sound transmission occurs through small openings.

The noise reduction of an enclosure depends on the transmission loss of the enclosure and the room constant (see Equation (23-9)). It can be computed as

$$NR = TL - 10 \log_{10}(1/4 + S_w/R) \qquad (23\text{-}15)$$

where

S_w is the exposed surface area of the enclosure (square feet)

R is the room constant (square feet)

Analysis must compare desired noise levels in decibels to measured noise levels to determine the noise reduction, NR, required at each band center frequency. Analysis adds an adjustment factor of about 5 dB to each difference to ensure that higher noise levels do not render the enclosure ineffective. The transmission loss, TL, is the sum of the required reductions and the value resulting from the expression involving the room constant in Equation (23-15).

23-7 MEASUREMENT

Measures

The human ear does not sense each frequency in the audible range with the same sensitivity. As a result, there is an adjustment to actual sound pressure levels to represent

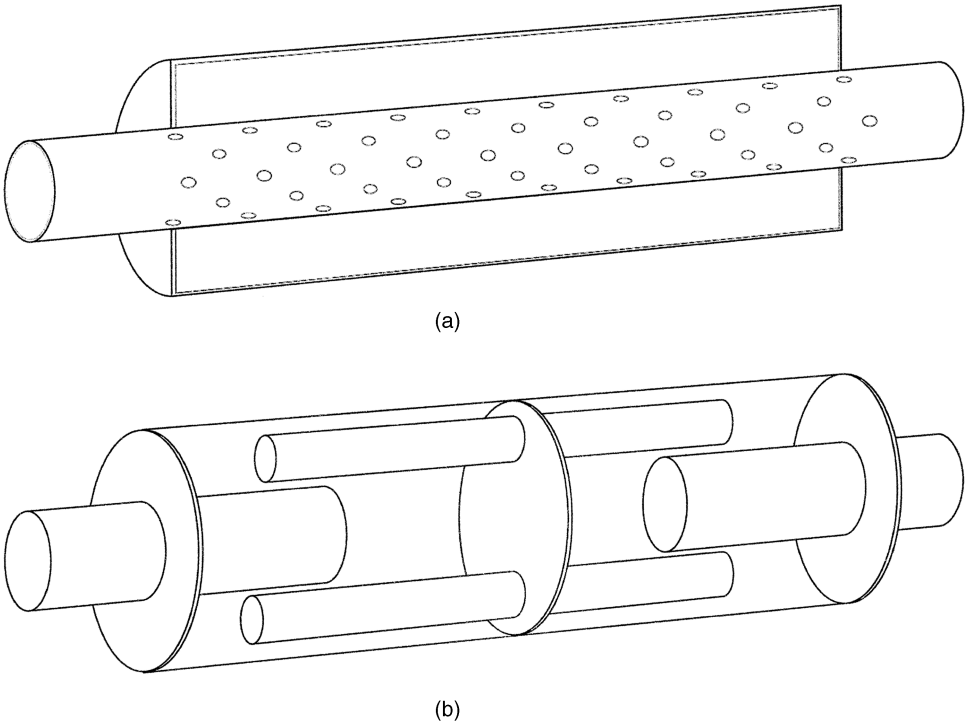


Figure 23-6. Two types of muffler designs. (a) A straight-through dissipative design. (b) A reactive type with baffle and tubes.

typical ear sensitivities. The most common weighting scale is the A scale. Other weighting scales are B, C, and D. Table 23-5 lists frequency weighting adjustments to convert physical sound pressure levels (decibels) to A scale values (A scale decibels, dBA).

Dosimetry

Many workers receive noise exposures that vary a lot during a workday. In 1981, OSHA required hearing conservation programs for workers exposed to TWAN levels greater than 85 dBA. Noise dose, *D*, measures varying exposures over a time period. A TWAN level is equivalent to an exposure of 90 dBA for an 8-hr period. OSHA exposure standards in Table 23-2 indicate that this is the maximum sound level permitted for an 8-hr period. Higher levels exceed the allowable dose. Noise dose in percent is

$$D = 100\,C/T \tag{23-16}$$

where

C is the total length of the workday in hours

T is the reference duration in hours for a measured A-weighted sound level L in decibels dBA

T is derived from an expansion of the OSHA exposure limits (Table 23-2) and is computed as

$$T = \frac{8}{2^{(L-90)/5}} \tag{23-17}$$

When noise exposure for a work shift consists of two or more periods of noise at different levels, the total noise dose over the workday is given by

$$D = 100\,(C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n) \tag{23-18}$$

The 8-hr TWAN sound level, in decibels, can be computed from noise dose:

$$TWAN = 16.61 \log_{10}(D/100) + 90 \tag{23-19}$$

Example 23-2 A worker has a noise exposure to a 107 dBA constant noise source during a 7-hr shift. What is the noise dose?

TABLE 23-5 Frequency Weighting Adjustments for Converting Sound Pressure Levels to A Scale Readings

Octave Band Center Frequency (Hz)	Correction (dB to dBA)
31.5	−39
63	−26
125	−16
250	−9
500	−3
1,000	0
2,000	+1
4,000	+1
8,000	−1
16,000	−6.6

From Equation (23-17), the reference duration is

$$T = \frac{8}{2^{(107-90)/5}} = \frac{8}{2^{3.4}} = 0.758 \text{ hr}$$

From Equation (23-16), the dose is

$$D = 100\,C/T = 100\,(7/7.58) = 92.3\%$$

Instruments

Sound Level Meter The most common sound measuring instrument is the sound level meter. It measures the sound level for each octave or for a broad band, normally about 20–20,000 Hz. On many of these meters, the user may select broad band or the octave of interest. The instrument measures sound arriving at a microphone. The instrument amplifies the signal. It may also filter the sound before providing a reading. Some sound level meters have digital displays and some have analog, moving indicator displays.

Readings are in decibels. Depending on the instrument features, a user may have a choice of filters or weighting scales. Some instruments have standard weighting scales for three filters: A, B, or C. The three weighting scales attempt to mimic the response of human hearing to low, medium, and high intensity sounds, respectively. On some instruments, users have a choice of fast or slow response readings. Slow responses may be easier to read on the display.

Meters require calibration against standard sound sources. Meter suppliers usually offer a calibration device. For most meters the device fits over the microphone and generates controlled sound sources.

Impulse Meter Sound level meters do not respond quickly enough for measurement of impulse sounds. Impulse meters provide this quick response. They give readings in decibels for peak levels of transient sound.

Frequency Analyzers A frequency analyzer measures the distribution of sound across one or more bandwidths. Frequency analyzers work on much the same principle as sound level meters. Typically, frequency analyzers give distribution readings by octave, although some can subdivide octaves into even smaller bandwidths. Distribution information is very helpful in assessing noise problems and pinpointing corrective action for high amplitude frequencies. Most design solutions involve particular bandwidths. Knowing the distribution helps with design decisions.

Dosimeters Many workers wear noise dosimeters during a work day. Some dosimeters are pocket-sized or smaller. A dosimeter continuously records the sound level. It may also integrate sound level over time relative to an 8-hr day to compute noise dose. By reading the integrated value, noise dose, at the end of the day, it is easy to determine if someone has exceeded the allowable noise dose.

Surveys

The only way to determine whether noise exceeds an exposure standard is to make measurements. A noise survey is a procedure for collecting noise in some space. There are two kinds of surveys. The intent of one kind is to establish whether an individual has an exposure that exceeds some standard. Noise dosimeters handle this kind of survey very well. They move with a wearer during the work day and capture the exposure data.

The other type of survey has the purpose of finding out if conditions could create excessive exposures. In this kind of survey, measurements taken at various locations help determine noise sources or potential noise exposures at locations where people may be. During a survey, a user takes readings with a sound level meter in a grid pattern or at specific worker locations. The survey data then help with decisions on reducing noise exposures.

23-8 VIBRATION

Background

Vibrations of the human body or parts of the human body may cause annoyance, affect performance, or cause trauma. There are many conditions that produce local or general vibration of the body. Studies have identified some effects. Data in the literature are not complete, since experiments on vibration may cause injuries. Existing data provide a picture of vibration hazards and suggest controls to prevent vibration-induced health and safety problems.

Physics

Vibration is repeated motion of an object or body. Frequency, displacement, amplitude, and force describe characteristics of vibrations. Frequency describes the rate of repetition, such as motions per second or minute. Displacement describes the range of movement involved, such as inches, mm or other units of length. Amplitude is another term for displacement. Force describes how hard a vibration motion applies to a body. Often the force is compared to the force of gravity. An expression is the number of "Gs" achieved. The laws of physics related to motion apply to vibrations.

Vibration involves acceleration and movement in various directions. The standard convention for acceleration of the human body is as follows:

Direction of Body Motion	Symbol
Forward	$+G_x$
Backward	$-G_x$
To right	$+G_y$
To left	$-G_y$
Headward	$+G_z$
Footward	$-G_z$

Physiology

Vibration motion may apply to the entire human body or to individual parts. The human body is a complex system of organs and tissue masses restrained by other tissue. Each type of tissue has properties that limit or dampen motion from vibration. Some tissues are elastic and have properties similar to springs. Trauma to tissues results when external vibrating forces accelerate the body or a body part and achieve amplitudes that exceed the capabilities of tissues. If the exciting frequency is a natural frequency of a body part, the resulting motion may produce severe damage. Amplitudes less than necessary for trauma can impede performance or be uncomfortable.

Hazards

Studies on whole body vibration suggest that truck drivers, tractor drivers, and heavy equipment operators have a greater incidence of back troubles than do people in other kinds of jobs. Drivers of such vehicles experience low frequency vibration in the 4–8 Hz range while seated. Spinal compression, length of exposure, and other factors may contribute to damage. Other factors may also contribute.

Consider the eye. The eyeball has a natural frequency of 60–90 Hz. Vibrations in this frequency range may interfere with visual tasks and might damage the retina or nerves connected to the eye. Large amplitudes may damage the supporting muscles and ligaments.

Assume an operator sits with arms extended to operate controls. If vibrations cause the operator's body to move vertically, the muscles of the arm may not be strong enough to hold the hands steady. That results in incorrect operation of the controls.

Vibration of the chest may create breathing difficulties. Vibration of the hands when using jack hammers and similar equipment can produce vibration-induced white finger or Raynaud's syndrome. Chapter 13 discussed this cumulative trauma disorder.

Table 23-6 lists approximate natural frequencies for various body parts. Figure 23-7 gives human response regions for vibration. These regions are not precise because effects are often a function of vibration direction.

TABLE 23-6 Approximate Natural Frequencies of Human Body Elements

Element	Natural Frequency (Hz)
Whole body, seated vertical	4–6
Whole body, prone	3–4
Whole body, standing vertical	5–12
Body seated on cushion	2–3
Head relative to body	20–30
Skull	300–400
Eyeball	60–90
Lower jaw relative to head	100–200
Shoulder and head, transverse	2–3
Hand	30–40

Standards

For several decades, the International Organization for Standardization (ISO) published several standards for shock and vibration of equipment. ISO also published standards for human exposure to mechanical vibration and shock.[7] One standard addresses hand–arm vibration syndrome (HAV). Another addresses whole-body vibration (WBV).

The American National Standards Institute has adopted the ISO recommendation in its standard.[8] ACGIH also relies on the ISO standards for Threshold Limit Values® related to human mechanical vibrations and shock. The Department of Defense also has standards on WBV particularly related to vehicles (Figure 23-8).[9] The DOD standards also tie to ISO standards on mechanical vibration and shock.

Controls

One control for vibration problems is to prevent applying vibration to the body or its parts. Another control is to reduce amplitudes to levels below those that can produce injury or interfere with performance. One must consider carefully the possible body parts involved. A third control is to model the vibrating system, including the human body, and then apply damping and/or springs that reduce the vibration and amplitude.

Measurement

Accelerometers measure vibration and acceleration. ISO standards on mechanical vibration and shock offer measurement recommendations. A reference on instrumentation for acceleration and vibration will help in establishing measurements.

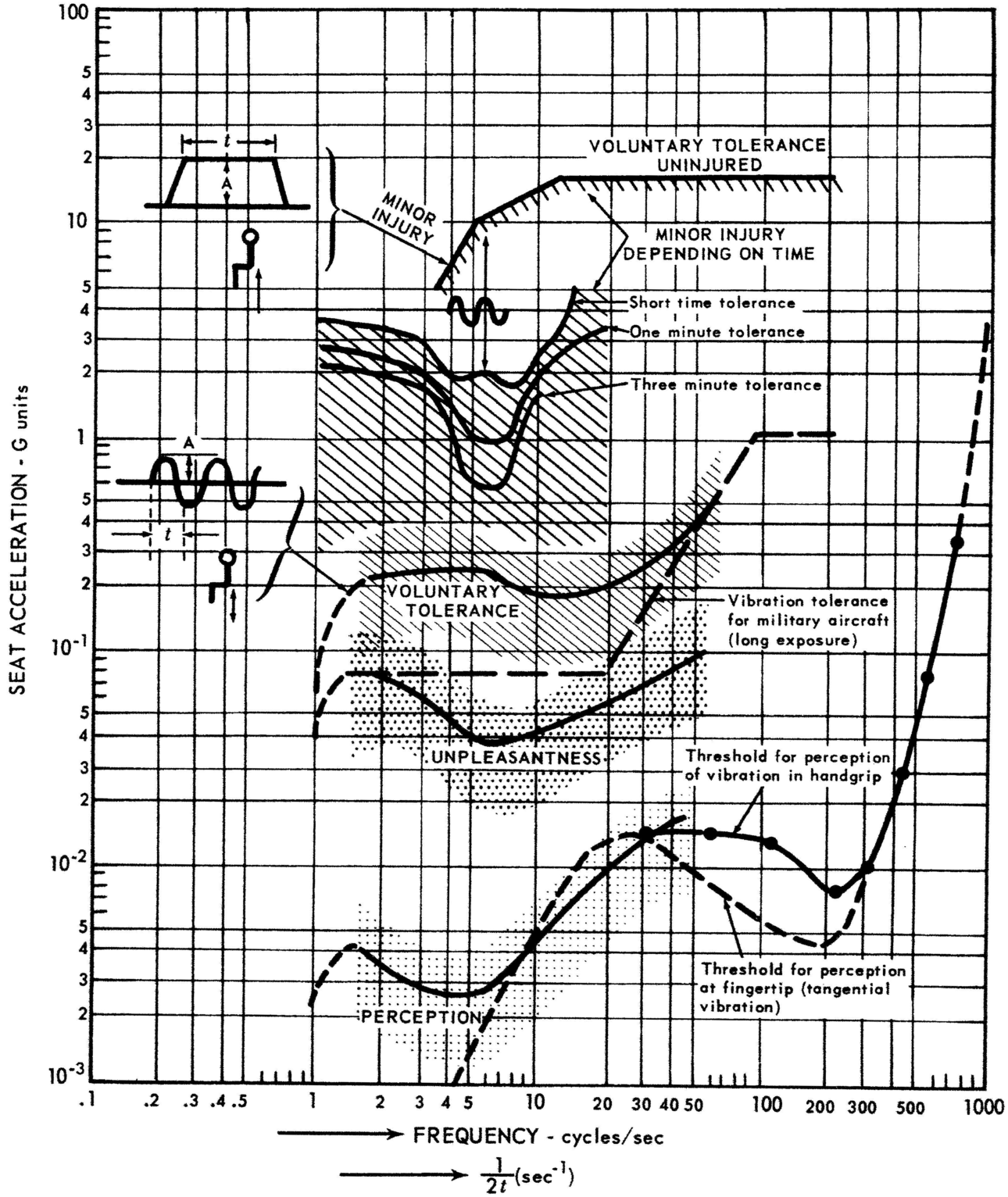
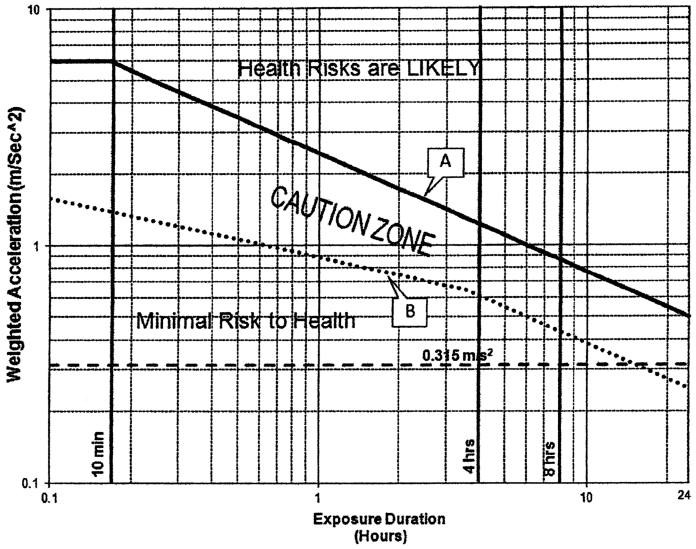


Figure 23-7. Human response regions for vibration. (From P. Webb, *Bioastronautics Data Book*, NASA SP3006, Washington, DC, 1964.)



Exposure duration (hrs)	Weighted Acceleration (m/sec^2)	
	Curve A	Curve B
0.1667 (10 min)	6.00	1.39
1.0	2.449	0.89
3.5	1.309	0.65
4	1.225	0.63
6	1.0	0.5
8	0.866	0.433
15	0.632	0.316
24	0.5	0.25

NOTE:

1. Curve A represents the upper zone associated with Equation B.1 in ISO 2631-1, Annex B, Amendment 1. Curve B represents the lower zone associated with Equation B.2 in ISO 2631-1, Annex B, Amendment 1 up to 3.5 hours exposure duration, and represents the lower zone associated with Equation B.1 in ISO 2631-1, Annex B, Amendment 1 beyond 3.5 hours exposure duration.

Figure 23-8. Health risks from whole body vibrations from vehicles. Refer to the source for additional implementing details. (From MIL-STD- 1472G)

EXERCISES

1. An employer made noise assessments for several operations in a plant. Some of the data appear in the accompanying table. The measurements were made at operator locations. For which operations are corrections mandatory according to OSHA exposure rules?

Operator location	Duration of daily exposure (hr)	Full-Scale reading (DBA)
A	3	100
B	1	97
C	8	88
D	5	96
E	1/2	110

2. A worker moves around among three operations each day. The duration and sound level for each are as follows:

Operation 1: 3 hr, 95 dBA
Operation 2: 4 hr, 90 dBA
Operation 3: 1 hr, 97 dBA

(a) What is the time-weighted average exposure value?

(b) Based on OSHA standards, is any protective action required?

3. For the exposure in Exercise 2, determine the noise dose, D.

4. A worker's noise dosimeter reads 65 at the end of an 8-hr day. What is the equivalent time-weighted average?

5. A machine produces a noise level Lp = 100 dBA for a worker located 5 ft from it (r = 5), where R = 500 ft^2 for the room and Q = 4. The machine will be installed in a new plant in a different arrangement than in the current plant. The worker distance from the machine r will be 15 ft, the room will have R = 2000 ft^2 and Q = 2. What will be the worker's noise exposure L_p in A scale decibels?
6. A room measures 50 ft wide, 70 ft long, and 12 ft high. It has a 90 dBA sound level from some source at a frequency of 1000 Hz. The surfaces in the room and their absorption coefficients are:

Surface	Absorption Coefficient at 1000 Hz
Ceiling	0.02
Floor	0.02
Walls	0.01
Covered pipe (180 ft^2)	0.50
Machinery (200 ft^2)	0.02
8 people	4 sabins/person absorption

To reduce sound levels, a company modified the room by covering the ceiling with acoustic tiles. The tile has an absorption coefficient of 0.80 at 1000 Hz.

(a) What noise reduction (NR) in decibels, is achieved?

(b) What is the resulting sound level in the room after modification?

7. A 25 ft-long duct has a cross-section of 6 ft × 4 ft. At one end a fan produces 100 dBA at all frequencies from 125–4000 Hz. If the duct has a 1-in.-thick glass fiber lining on all surfaces, compute the reduction in sound exiting the far end of the duct for the following frequencies:

(a) 125 Hz

(b) 500 Hz

(c) 2000 Hz

8. An enclosure is made of ½-in.-thick plywood. Inside the enclosure is a noisy machine. Determine what reduction in noise will actually occur at 1000 Hz if:

(a) there is a 20% opening in the enclosure

(b) there is a 5% opening in the enclosure

9. Noise in an automated production area exceeds OSHA limits. One solution is to provide a full enclosure room in the production area to reduce the duration of potential exposure to noise for employees. The workers can spend the greater part of the day performing tasks within the enclosure, observing operations through windows. They can wear hearing protection when they enter the automated production area to take samples or make adjustments. The sound levels in the production area are as follows:

Octave Band Center Frequency (Hz)	Production Area Sound Level (dBA)
125	88
250	90
500	91
1000	92
2000	93
4000	89

(a) Compare the resulting noise levels for two alternate wall materials

1. 4 in. dense aggregate concrete block
2. ½ in. gypsum board on 2 × 4 studs, 16 in. O.C.

(b) Plot the original and resulting sound levels by octave band.

10. A highway construction worker drives an asphalt pavement roller. He works an 8-hour shift. If the machine vibrates the driver at 4 Hz and produces a seat acceleration of 0.5 m/s^2, is a health risk likely?

REVIEW QUESTIONS

1. Define noise.
2. What frequencies do people hear?
3. Name the units of measure for the following:
   (a) sound amplitude
   (b) sound power
   (c) sound pressure
   (d) sound intensity
   (e) sound pressure level
   (f) sound frequency
   (g) sound absorption
4. What is the significance of the A weighting scale when measuring sound?
5. Give the main anatomical parts of the following:
   (a) outer ear
   (b) middle ear
   (c) inner ear
   (d) cochlea
6. What is an audiogram?
7. Identify five effects of noise on people.
8. Explain the following:
   (a) bone conduction

(b) temporary threshold shift

(c) permanent threshold shift

(d) acoustic trauma

(e) startle response

9. What average sound pressure level in dBA is the maximum allowed in standards during an 8-hr period?

10. At what sound level does OSHA require a hearing conservation program?

11. What are the main types of controls for noise?

12. Give an example for controlling noise:

(a) at its source

(b) along its path

(c) at the receiver

13. Explain noise dose.

14. What three parameters describe vibration-induced motion?

15. List the hazards of vibration for:

(a) the whole body

(b) the arms

(c) the head

(d) the hands

(e) the chest

16. What controls can reduce vibration dangers?

NOTES

1 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9735

2 Refer to Section 23-7 for a discussion of the A noise weighting scale.

3 *2015 TLVs® and BEIs®*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 2015 (updated annually).

4 https://osha.europa.eu/en/legislation/directives/exposure-to-physical-hazards/osh-directives/82

5 www2.epa.gov/aboutepa/epa-identifies-noise-levels-affecting-health-and-welfare

6 http://ec.europa.eu/environment/noise/directive.htm

7 ISO 5349, *Mechanical Vibration: Measurement and Assessment of Human Exposure to Hand-Transmitted Vibration*, International Standards Organization, Geneva. ISO 2631, *Guide for the Evaluation of Human Exposure to Whole-Body Vibration*, ISO, Geneva.

8 ANSI S2.70, ANSI S3.18

9 MIL-STD-1472, *Design Criteria: Human Engineering*, U.S. Department of Defense.

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CHAPTER 24

CHEMICALS

Chemicals are the basic elements of life and the world around us. Chemical products fill our homes. Materials made from chemicals are found in cars, clothing, furniture, tools, food, and other things we use and contact daily. Most chemicals are not dangerous. Many chemicals and compounds are beneficial. Some are dangerous and may cause harm. There are many factors involved in deciding about risks related to chemicals. This chapter explores information for determining risks and preventing harm.

The production and use of chemicals are fundamental to all economies. The global chemical business exceeds $1.7 trillion annually.

The public has a high level of concern over chemicals. There are many books on chemicals and the dangers of chemicals. Is the public concern valid? Are people unnecessarily afraid of chemicals? Certainly events like those cited in Cases 24-1, 24-2 and 24-3 raise public concern. There are many other events involving chemicals that gained national attention. Included are:

Love Canal, New York[1] (Case 27 – 1)
Times Beach, Missouri (Case 27-2)
Bullitt County, Kentucky (Smith's Farm and Valley of the Drums; Case 24-3), and
Union Carbide release in Institute, West Virginia

The purpose of this chapter is to explore the hazards and controls for dangerous chemicals, not to pass judgment on public issues. Readers should study the issues and form their own opinions.

The Chemical Abstract Service (CAS) Registry has more than 90,000,000 organic and inorganic substances with about 16,000 added per day. CAS lists more than 65 million protein and DNA sequences. CAS has a database (CHEMLIST) of about 315,000 regulated substances. More than 60,000 chemical compounds have significant economic value and are in the marketplace.

There are published exposure standards for more than 500 chemical compounds. The National Library of Medicine identifies databases[2] (TOXNET) on toxicology, hazardous chemicals, environmental health, and toxic releases. EPA[3] and OSHA[4] have lists of hazardous chemicals.

When considering the hazards of chemicals, several factors are important:

- Compounds that have known hazards may not be hazardous at low concentrations.
- Compounds that are not normally dangerous may become so for certain uses.
- Some compounds become dangerous when combined with others.

Like other hazards, there is a need to learn about some of these chemicals, their dangers, use, and disposal.

This chapter cannot cover all the compounds important for safety and health. One can find hazardous compounds in many conditions, situations and uses. This discussion focuses on an understanding of chemical hazards and their control.

24-1 CHEMICAL REGULATIONS AND STANDARDS

Indoors

Concern about indoor air quality continues to grow. Several federal agencies regulate chemicals in indoor air. OSHA regulates the workplace. EPA regulates some public places. DOT regulates public transportation, such as aircraft, trucking and railways. Many state and local governments and individual organizations have additional laws, regulations, and recommendations for indoor air quality. For example, since 1987 many local government organizations and private companies have banned smoking in public places and workplaces or restricted smoking to particular areas.

Not all exposures to chemicals in the workplace occur through the air. For many years the American Conference of Governmental Industrial Hygienists (ACGIH) has published recommendations[5] on workplace exposures to hazardous chemicals.

For a long time little attention was paid to indoor air quality for other than workplaces. However, some organizations have begun to address the problem. In the 1930s and even before, the American Society of Heating, Refrigeration

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 24-1

December 3, 1988. Bhopal, India. Many describe this event as the world's worst industrial tragedy. During predawn hours at the Union Carbide plant, as much as 40 tons of methyl isocyanate gas leaked from a storage tank at the chemical plant. The gas settled over a 15 square mile area populated by more than 200,000 people. Local residents call this "Devil's Day." The chemical release killed more than 3,000 and injured more than 20,000. Some reports state that over 50,000 people received medical treatment the first day. Many injuries involved damage to eyes and mild to severe pulmonary disorders. Health issues remain 30 years later for many victims.[a, b, c, d]

This disaster was one of the most publicized, evaluated, penalized and written about chemical disasters on record. Litigation lasted for years.

[a] www.bhopal.com/
[b] www.youtube.com/watch?v=yt9F520v16s
[c] www.ncbi.nlm.nih.gov/pmc/articles/PMC1142333/
[d] http://cseindia.org/userfiles/THE%20BHOPAL%20DISASTER.pdf

CASE 24-2

1973, Michigan. Somehow about 1,000 lb of flame-retardant chemical called polybrominated biphenyl (PBB) became accidentally mixed into livestock feed in Michigan. Suppliers unknowingly distributed the feed to farms throughout the state. The chemical had already found its way into the human food chain by the time authorities identified the problem. The state quarantined 500 farms. As a result, the state ordered the destruction of more than 30,000 cattle, 4,500 swine, 1,500 sheep, and 1.5 million chickens. In addition, the state destroyed 800 tons of animal feed, 18,000 pounds of cheese, 2,500 pounds of butter, 5 million eggs, and 34,000 pounds of dried milk products. About 85% of Michigan's population received some exposure to PBB through the food chain. Researchers found PBB in 97% of tissue samples taken from adults across the state. Studies of some exposed in this incident identified that it takes on average about 10–13 years for the level of PBB in human tissue to reduce by half. Long-term epidemiological studies continue on Michigan residents.[a, b, c, d]

[a] www.michigan.gov/documents/mdch_PBB_FAQ_92051_7.pdf
[b] www.taoslandandfilm.com/independent-films/Cattlegate-Michigan-PBB-documentary#.VOzlmC5BlpM
[c] http://stacks.cdc.gov/view/cdc/3943/cdc_3943_DS1.pdf
[d] Edwin Chen, *PBB: An American Tragedy*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1979.

CASE 24-3

1984, Bullitt County, Kentucky. One of the first sites selected for Superfund cleanup was an abandoned 30-acre site. It became known as the Valley of the Drums, located on the Smith Farm near Brooks, KY. Estimates indicated that 100,000–200,000 drums are buried or partially buried on the site. Some contain waste, but the contents of all are not known. There are numerous streams of leachate at the site. Many drain into a tributary to the Bluelick Creek, a source of drinking water for potentially 300 people.

The initial Superfund cleanup project removed about 2,000 drums of waste from the surface of the site. Later projects addressed removal of more drums and other remedial actions.[a]

[a] http://epa.gov/region4/superfund/sites/npl/kentucky/altayky.html

and Air Conditioning Engineers (ASHRAE) recommended ventilation rates for indoor space. Many building codes incorporated their recommendations. Energy conservation in buildings, reduced ventilation rates and tighter construction that limits air infiltration produced a renewed interest in indoor air. ASHRAE, the American Institute of Architects and other organizations held conferences on indoor air quality. Standards organizations also produce indoor air quality standards. Undoubtedly, indoor air quality will be an active topic for some time and result in new and revised standards.

Outdoors

For outdoor environments there are many laws and regulations governing air and water quality and the handling and disposal of hazardous material. In addition, there are laws governing the cleanup of sites containing hazardous materials.

Air Congress passed the Clean Air Act in 1970 and renewed it in 1977 and 1990. Its goal was to protect public health, improve atmospheric visibility, and prevent damage to crops by controlling emissions from industrial plants and automobiles and imposing controls on common air pollutants. Other environmental laws impact air quality as well.

Water Congress passed several laws affecting water quality, including the Clean Water Act of 1972, which set limits on toxic discharges of industry and created a large public works program to build sewage treatment plants. The Safe Drinking Water Act of 1974 sets standards for the taste, color and appearance of public drinking water and maximum limits for certain chemicals and bacteria it contains. The Federal Water Pollution Control Act of 1977 extended previous regulation of water quality. The Marine Protection, Research and Sanctuary Act of 1972 banned ocean dumping of radioactive, biological, and chemical warfare wastes. It established a permit system for ocean dumping of other wastes, such as sewage sludge and dredged materials.

Control of Hazardous Materials The Federal Insecticide, Fungicide and Rodenticide Act of 1972 required registration of all pesticides. It required manufacturers to submit detailed information about pesticide ingredients and safe use. The Resource Conservation and Recovery Act of 1976 (often referred to as RCRA) authorized regulation of the generation, treatment, storage, and disposal of hazardous wastes. It established a manifest system for tracking hazardous materials from creation to disposal or use. It eliminated open landfills. Congress passed the Toxic Substances Control Act (often called TSCA) in 1976. It required testing of new chemicals for safety before they reach the marketplace. The Hazardous Materials Transportation Act (discussed in Chapter 14) controls the packaging, labeling, and transportation of hazardous materials.

Cleanup In 1980, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (sometimes called CERCLA), which addressed the cleanup of existing hazardous waste sites. This "Superfund" bill requires industry to contribute to the cost of cleaning up sites containing hazardous materials. An EPA survey of states identified about 35,000 hazardous waste sites. In 1986, Congress passed the Superfund Amendments and Reauthorization Act (called SARA), which extended the Superfund and hazardous waste site cleanup. Not all waste sites contain hazardous waste.

The volume of hazardous waste sites is difficult to ascertain. For example, a study of two counties in New York State identified sites with some amount of hazardous waste.[6] In Niagara County (Niagara Falls area), the study identified 102 sites. In Erie County (Buffalo area), there were 100 sites. Some sites listed in the report had been inactive for years and the contents were not known.

Right-to-Know and Hazard Communication Public demand for more information about the dangers of particular chemicals led to federal and state right-to-know laws. Under the Emergency Planning and Community Right-to-Know Act of 1986 (also known as SARA Title III) employers must inform employees within and citizens outside a plant about the dangers of chemicals at the site. Material safety data sheets (MSDS) standardize the information and give details about chemicals or compounds and applicable protection from harm when exposed to them. SARA Title III also covers labeling and storage requirements and allows states to pass right-to-know laws that require emergency planning for communities around a plant.

The United Nations led a global action to identify chemical hazards, classify chemical hazards logically, and communicate hazard information. This international activity led to *The Globally Harmonized System of Classification and Labelling of Chemicals*.[7] The system has the acronym GHS. In the details, there are standard methods for labeling chemicals. There are also standards for Safety Data Sheets (SDSs) intended to communicate chemical properties and hazards. The United States recently adopted this system.[8]

Companies analyze process plant safety and develop emergency response plans in coordination with local police, fire departments, and other organizations in neighboring communities.

Products

There are also regulations covering chemicals in certain products. For example, food additives and coloring agents fall under the control of the FDA. It also controls certain

CASE 24-4

1977. One action of the CPSC that received much public attention occurred in 1977. It involved the recall and banning of children's sleepwear containing a fire-retardant material known as TRIS.[9] After pressure to prevent the horrors of sleepwear (particularly dacron) burning and melting into the skin of children, Congress required a fire retardant for the sleepwear. TRIS was the material most often used. Not only was it an effective fire retardant, but it also retained properties in the clothing that made the sleepwear soft and saleable. However, it was suspected of being a cancer-causing agent. Researchers began health studies to establish if TRIS was a carcinogen. Before results were known, Congress faced public pressure to protect children's health. It put pressure to act on CPSC.

The Commission tried to balance economic, health, and political factors. TRIS retained the feel necessary to induce customers to buy sleepwear, whereas other additives gave fabric a coarse feel. With each washing, the TRIS content of sleepwear decreased about 50%. A few washings would remove any potentially dangerous levels from already-purchased clothing. The sleepwear industry was a collection of small firms dedicated to producing this clothing. The CPSC ultimately decided to recall TRIS-treated sleepwear. The action seriously harmed the industry, while protecting children against an undetermined hazard. Sleepwear with flame-retardant protection as required by law was no longer available. As an alternative, many parents purchased non-fire-retardant insulated sleepwear. The problem was back to where it started.

The problem of fire-retardant and other treatments in children's sleepwear continues today. Some recent studies create health concerns with today's products.

chemicals in cosmetics. The Consumer Products Safety Commission (CPSC) regulates the chemicals in a variety of consumer products.

Workplaces

There are many standards for exposures to chemicals. Some cover employees, others set levels of contaminants in drinking water and air. Some focus on consumer products (cosmetics, food, clothing, etc.), while others cover agricultural uses. One should refer to appropriate federal agencies for current exposure standards for chemicals. This discussion will focus on standards for workers.

Threshold Limit Values® (TLVs) For many years the American Conference of Governmental Industrial Hygienists has published a booklet listing the recommended exposure limits for workers.[10] It is a guide to help limit harmful chemical exposures for workers. It does not distinguish safe from harmful exposures. The Threshold Limit Values® (TLVs) include exposures to airborne particulates and gases or vapors. An ACGIH committee updates the "TLV Guide" annually. Changes result from careful review of research literature and monitoring of reported experience. The ACGIH also publishes background data for the information found in the "TLV Guide."

ACGIH exposure standards apply to 8-hr time-weighted average exposures (TWA). They allow for reasonable exposure variations during a workday. For some chemicals, ACGIH lists ceiling limits: Exposures should never exceed these values. In addition, some TLVs have a "skin" notation for substances, indicating substances are absorbed easily through the skin. Some ACGIH recommendations have 15-min exposure values because of dangers for very short-term exposures. These are Short-Term Exposure Limits (STELs).

OSHA Permissible Exposure Limits (PELs) OSHA exposure standards are Permissible Exposure Limits (PELs) for workers. They are also 8-hr time-weighted averages. Since their first publication in 1970, few have changed and do not reflect the latest knowledge about effects of some chemicals. The standards remain enforceable standards by the agency.[11]

NIOSH Recommended Exposure Limits (RELs) The National Institute of Occupational Safety and Health (NIOSH) publishes Recommended Exposure Limits (RELs).[12] NIOSH updates them periodically. NIOSH only makes recommendations. It is not an enforcement agency. RELs provide guidance.

Mixtures Some people have exposures to more than one substance during an 8-hr period. The exposures may involve different substances at different times during the work day or exposure to a mixture of different substances at the same time. In some cases the chemicals may have independent effects. Each affects a different organ or acts in a different way on the body.

In other cases, the chemicals may react with each other and have a synergistic effect. When exposures involve two or more hazardous substances that act on the same organ, one should address synergistic effects. When there is little or no information about combined effects, it is best to consider

additive effects. One can evaluate additive effects by using

$$X = C_1/T_1 + C_2/T_2 + ... + C_n/T_n \qquad (24\text{-}1)$$

where

C_x is the atmospheric concentration of a substance

T_x is the threshold limit value

If $X \leq 1$, the mixture does not exceed the TLV. If $X > 1$, the mixture exceeds the TLV.

Example 24-1 During an 8-hr workday, a worker has exposures to the following mixture of substances:

Acrylic acid : 4 ppm
Stoddard solvent : 60 ppm
Ethyl ether : 230 ppm

From OSHA Table Z-1,[13] the Permissible Exposures Limits for these substances are 10, 500 and 400 ppm, respectively.

Applying Equation (24-1),

$$X = 4/10 + 60/500 + 230/400 = 1.095$$

Because $X > 1$, the mixture exceeds the threshold limit value.

Biological Exposure Indices (BEIs) Biological monitoring consists of an assessment of overall exposure to chemicals that are present in a workplace through measurement of appropriate determinants in biological specimens collected from workers. Biological determinants can be the chemical itself, its metabolite(s) or a characteristic reversible biochemical change induced by the chemical. One must make appropriate measurements on exhaled air, urine, blood, or other biological specimens. Biological Exposure Indices® serve as reference values. They represent the levels of determinants that are most likely to be observed in specimens collected from a healthy worker who has been exposed to chemicals to the same extent as a worker with inhalation exposure to the TLV-TWA.

ACGIH publishes BEIs as reference values. They intend to help with evaluation of potential health hazards in the practice of industrial hygiene. BEIs apply to 8-hr exposures, five days a week. Individual differences may account for occasional measurements above BEIs. If a sample exceeds a BEI consistently, there is cause for investigation of the workplace. BEIs should have a backup method for assessing exposures. They are not the primary means for determining if a hazard exists.

24-2 HAZARDS

Chapter 9 introduced hazard recognition and control. The discussion notes that one must know at least three items of information about an agent to determine if it is hazardous:

- what the agent is and what form it is in
- the concentration
- the duration and form of exposure

This is important to understand hazards and controls for chemicals. The main hazards for chemicals are

(a) health effects
(b) fires and explosions
(c) reactivity with other materials.

This chapter mainly discusses health effects. Chapters 16 and 17 discussed fire and explosion hazards. Reactivity refers to the relative stability of a material. In a fire a material may become unstable from the heat or products of combustion. Some materials may be sensitive to mechanical disturbance from pressure or physical impact. Extinguishing agents, such as water, can react with certain materials. A reaction may involve releases of large amounts of energy and the release may be sudden, as in an explosion.

Classifications

There are several ways to classify hazardous materials. Chapter 14 discussed the DOT classification and labeling of hazardous materials. As noted, the DOT modified its system to be consistent with the United Nations' system (see Notes at the end of this chapter).

Another classification system is that covered in NFPA 704.[14] A diamond-shaped symbol, divided into quadrants, conveys health, flammability, reactivity, and other special information (see Chapter 16, Figure 16-4).

Identification

There are several ways to identify chemicals. Each chemical or compound has a chemical name and chemical formula. Examples are ozone (O_3) and methyl isocyanate (CH_3NCO). The Chemical Abstract Service has a system for assigning a unique CAS Registry Number[15] in the format xxx-xx-x. For example, ozone and methyl isocyanate are 10028-15-6 and 624-83-9, respectively.

NIOSH maintains the Registry of Toxic Effects of Chemical Substances (RTECS),[16] which assigns each listed chemical a unique number. Examples are RS8225000 and NQ9450000 for ozone and methyl isocyanate.

As noted in Chapter 14, DOT has an identifying number for hazardous materials as does the United Nations. Numbering systems for procurement purposes, such as the federal National Stock Numbers, also identify chemicals.

Type of Airborne Contaminants

There are two main forms of airborne contaminants. There are particulates and gases or vapors.

Particulates Particulates include dusts, fumes, smoke, aerosols, and mists. Particulates also have classifications by size and chemical makeup. Shape can also be important. For example, some particulates have long, thin, fibrous shapes. Others may be spherical and have a fairly uniform cross-section. Figure 25-5 (Chapter 25) provides size characteristics of some airborne contaminants.

Dusts Dusts are airborne solids, typically ranging in size from 0.1 to 25 μm. Dusts larger than 5 μm settle out in relatively still air due to the force of gravity. Processes that break materials into small sizes, such as grinding and mixing, usually create dusts.

Fumes Fumes are fine solids less than 1 μm in size often formed by condensation of vapors. For example, heating of lead vaporizes some lead material that quickly condenses to small, solid particles.

Smoke Smoke is carbon or soot particles, generally less than 0.1 μm in size. Smoke results from incomplete combustion of materials containing carbon.

Aerosols Aerosols are airborne solid or liquid particulates dispersed in air.

Mists Mists are fine liquid droplets suspended in or falling through air. Condensation of a material from the gaseous to the liquid state often produces mists. In other cases, atomizing, splashing or foaming actions break up liquids into fine particles.

Gases Gases are a state of matter separate from solids and liquids.

Vapors The gaseous phase of a substance that is liquid at normal temperature and pressure.

Health Effects

Health effects vary considerably for different chemicals. The likelihood and degree of damage depend on several characteristics of a chemical. Main factors are type and form of substance, type and rate of exposure, and what happens to the substance in the body. Most hazardous materials affect particular organs of the body. For example, some will damage tissue, such as skin and eyes, on contact. Some affect respiration. Some damage nerves and other elements of the central nervous system. Some affect oxygen transport by the blood or other blood functions.

General symptoms, such as headache and nausea, occur with exposure to many chemicals. They also occur with other diseases. By themselves, such symptoms do not point to a specific chemical exposure. Someone may not recognize a chemical exposure as a cause for these symptoms.

Some effects of chemicals appear as behavioral changes. For example, lead exposure may lead to forgetfulness, hallucinations, and lethargy. Exposure to mercury or mercury compounds can lead to behavioral changes such as neural sensory impairment and emotional instability associated with Mad Hatter disease[17] referenced in *Alice in Wonderland*. Behavioral symptoms resulting from chemical damage are often confused with other causes.

Latency Period Some chemicals have immediate effects. An example is strong acid or caustic damaging tissue upon contact. These are called "chemical burns" because they exhibit properties similar to thermal damage of tissue. Other chemicals may not manifest their effects for some time. A latency period is the delay between exposure and observable effects. Some cancer-causing materials have a latency period as long as 20–40 years.

Acute Versus Chronic Exposures Exposures can be acute or chronic. For some chemicals, a single exposure is sufficient to induce an effect. For other chemicals, disease or effects do not appear until after repeated exposures. Some materials will not cause permanent damage with a single exposure. Other materials require one exposure to cause damage. Some may not cause permanent damage at all.

Local Versus Systemic Effects Local effects occur when substances cause injury to skin, eyes, or the respiratory tract following one or more exposures. Systemic effects occur when substances enter the body and produce damage to organs or impact biological functions. The effects may be physical or behavioral. Examples of damage from some exposures may include kidney dysfunctions or failures, changes in clotting of blood, damage to liver tissue and function, and ulcerations in the digestive tract.

Asphyxiates Asphyxiate materials do not have direct effects on the body or its organs. However, they do displace oxygen in a breathing atmosphere. The reduced oxygen content in inhaled air affects the partial pressure of oxygen and inhibits oxygen transport in the blood (see Chapter 19). Some asphyxiates may interfere with oxygen transport or breathing in other ways.

Nuisance Dusts Some materials are simply a nuisance. They may cause irritation, coughing or similar symptoms, but have no long-term effects. Certain dusts are classified as nuisance dusts.

Individual Differences Not everyone exhibits the same effects or degree of effects from a chemical exposure. Two people may have the same exposure but only one may show a

reaction. Some people are allergic to certain materials. An individual may inherit an allergic reaction or develop an allergy during life. Some people become sensitized to a substance following one or more exposures. Initially, they do not react to an exposure, but then suddenly they show reactions. Removal of the substance may stop the reaction. However, someone becomes sensitized to the substance. Following sensitization, a single additional exposure can trigger the allergic reaction.

Pneumoconiosis Pneumoconiosis is a disease of the lungs resulting from the inhalation of certain kinds of dusts or other particles. The term simply means dusty lung. The disease has several names depending on the material involved in an exposure. Table 24-1 lists several forms of pneumoconiosis.

There are other forms of lung disorders related to exposures to hazardous materials. Fibrosis is the formation of scar tissue. The tissue forms when the body attempts to engulf foreign material that lodges in the lung. Bronchitis is the overproduction of mucus, which often results in coughing. Asthma is the constriction of the bronchial tubes caused by a histamine reaction to some toxin that produces swelling. Hives on the skin is a similar histamine reaction.

Carcinogens A substance that produces cancer in animals or humans under certain quantified exposures is a carcinogen. Some define a carcinogen as any agent that increases tumor induction in man or animals. Even the induction of benign tumors may be enough to characterize a substance as a carcinogen. Irreversibility and a long latency period following the initial exposure to a carcinogenic agent characterize carcinogenesis. There are specific tests to determine when a material is classified as a carcinogen or a suspected carcinogen.

Mutagens A mutagen is any substance that causes changes in the genetic structure in a current generation of animals or humans such that it can cause cancer or some mutation in a later generation. Some mutations may not show up until several generations later. Mutagens cause inheritable changes in the chromosomes. The changes may not be observable deformities. Ionizing radiation, for example, has been associated with sterility as a mutagen.

Teratogens A teratogen is any substance that causes malformations or serious deviations from the normal in a human or animal fetus. Congenital malformations or abnormalities in offspring resulting from exposure of a mother or fetus to some agent is teratogenesis. Typically there is no exposure effect for the mother. Teratogens interfere with normal embryonic development.

24-3 TOXICOLOGY

Toxicity is the capacity of a material to produce injury or harm once it reaches a site in or on the body where harm can result. In contrast, a health hazard is the possibility that exposure to a toxic material will cause harm under ordinary use circumstances or when someone uses a specific quantity under particular conditions. Toxicology is the science that deals with the nature and effects of poisons. Tables 24-2 and 24-3 summarize some toxicity rating schemes.

Sources of Data

There are publications that list toxic properties and associated information about chemical substances. One of the primary references is *Sax's Dangerous Properties of Industrial Materials*.[18] This long-standing publication lists toxicity and other data for about 28,000 substances.

The OSHA Hazard Communication Standard[19] requires that chemical manufacturers and importers provide customers with material safety data sheets (MSDSs). With the switch to the Globally Harmonized System of the United Nations (see note 7), the new reference documents are called Safety Data

TABLE 24-1 Types of Pneumoconiosis

Disease	Material Inhaled
Asbestosis	Asbestos fibers
Silicosis	Free silica (SIO_2) dust from mining, sandblasting, quarrying and in ash from volcanic eruptions
Berylliosis	Beryllium particles
Byssinosis	Cotton dust
Metal fume fever	Particulates of zinc, magnesium, copper and their oxides (other metals have also been known to produce metal fume fever)
Siderosis	Iron oxide (often from welding and mining)
Kaolinosis	Kaolin (china clay) dust from grinding and handling
Mica pneumoconiosis	Mica dust from grinding
Bauxite pneumoconiosis (Shaver's disease)	Aluminum oxide fumes from smelting bauxite

TABLE 24-2 Toxicity Rating System[a]

Rating	Description
U	**Unknown.** Insufficient data are available to enable a valid assessment of toxic hazard to be mad.
0	**None, no toxicity**. This rating applies to chemicals that (a) produce no toxic effects under any conditions of normal usage or (b) require overwhelming doses to produce any toxic effects in humans.
1	**Low, slight toxicity**. The rating is characterized under four types of exposure: (a) *Acute local*. Chemicals that on a single exposure lasting seconds, minutes or hours cause only slight effects on the skin or mucous membranes or eyes, regardless of the extent of exposure. (b) *Acute systemic*. Chemicals that can enter the body by inhalation, ingestion or dermal contact and produce only slight toxic effects, regardless of the duration of exposure or following the ingestion of a single dose, regardless of the amount absorbed or the extent of the exposure. (c) *Chronic local*. Chemicals that on repeated or continuous exposure covering days, months, or years cause only slight and reversible damage to the skin or mucous membranes. The extent of the exposure can be great or small. (d) *Chronic systemic*. Chemicals that on repeated or continuous exposure covering days, months, or years cause slight and usually reversible toxic effects on the skin, mucous membranes, or eyes. The exposure can be by ingestion, inhalation, or skin contact and may be great or small. Slightly toxic chemicals produce changes readily reversible once the exposure ceases with or without medical intervention.
2	**Moderate toxicity.** Chemicals may cause reversible or irreversible changes in the human body not necessarily severe enough to cause serious physical impairment or threaten life. Ratings are characterized under four types of exposure: (a) *Acute local*. Chemicals that on a single exposure lasting seconds, minutes or hours produce moderate toxicity to the skin, mucous membranes, or eyes. The effects can be the result of an intense exposure for seconds or a moderate exposure for hours. (b) *Acute systemic*. Chemicals that after being absorbed by inhalation, ingestion or skin contact produce moderate toxicity after a single exposure lasting seconds, minutes or hours or after the ingestion of a single dose. (c) *Chronic local*. Chemicals that on continuous or repeated exposure over days, months or years cause moderate toxicity to the skin, mucous membranes, or eyes. (d) *Chronic systemic*. Chemicals that on absorption by ingestion, inhalation or skin contact cause moderate toxicity after continuous or repeated exposures over days, months or years.
3	**High, severe toxicity.** Ratings are characterized under four types of exposure: (a) *Acute local*. Chemicals that on a single exposure covering seconds or minutes can cause injury to the skin, mucous membranes, or eyes of sufficient severity to threaten life, cause permanent physical impairment or disfigurement. (b) *Acute systemic*. Chemicals that after a single exposure by inhalation, ingestion or skin contact cause injury of sufficient severity to threaten life. The exposure may last seconds, minutes or hours or may be a single ingestion. (c) *Chronic local*. Chemicals that on continuous or repeated exposures covering days, months or years can cause injury to the skin, mucous membranes, or eyes of sufficient severity to threaten life or produce permanent impairment, disfigurement or irreversible change. (d) *Chronic systemic*. Chemicals that on continuous or repeated exposures by inhalation, ingestion or dermal contact to small amounts for days, months or years can produce death or serious physical impairment.

Note: [a] From N. I. Sax, *Dangerous Properties of Industrial Materials*, 7th ed., van Nostrand Reinhold, New York, 1988.

Sheets (SDSs). These data sheets are good sources of information about the toxicity and other physical, chemical and hazardous properties of chemicals. Table 24-4 lists the elements OSHA requires on Safety Data Sheets (SDSs).[20]

There are also some computer-accessible data banks of toxicity data for substances. The most noteworthy one mentioned earlier in this chapter is TOXNET of the National Library of Medicine (see note 2).

TABLE 24-3 Degree of Toxicity Ratings

Toxicity Rating	Probable Lethal Dose	Experimental LD_{50}: for a 70 kg Human Dose per kg of Body Weight
Dangerously toxic	A taste	< 1.0 mg
Seriously toxic	A teaspoonful	1–50 mg
Highly toxic	An ounce	50–500 mg
Moderately toxic	A pint	0.5–5 g
Slightly toxic	A quart	5–15 g
Extremely low toxicity	More than a quart	> 15 g

TABLE 24-4 Elements OSHA Requires on Safety Data Sheets (SDSs)

- Product identification
- Hazard(s) identification
- Composition and ingredients
- First-aid measures
- Fire fighting measures
- Accidental release measures
- Handling and storage
- Exposure controls and personal protection
- Physical and chemical properties
- Stability and reactivity information
- Toxicological information
- Ecological information
- Disposal considerations
- Transport information
- Regulatory information
- Other information and security

Routes of Entry

There are three main routes of entry for hazardous substances into the body: inhalation, ingestion, and absorption through the skin. An occasional route of entry is injection. Once materials enter the body and reach the blood, circulation will distribute the substance throughout the body. Some materials have an affinity for certain kinds of tissue and, consequently, concentrate in particular organs. The most common routes of entry in work environments are by inhalation or absorption through the skin.

Inhalation During respiration, airborne gases and particulates move into the upper respiratory system and lungs. Figure 24-1 illustrates the structure of the respiratory system. Air passes through the pharynx and trachea to the bronchi, bronchioles, and ultimately to the terminal air sacks or alveoli.

Gases and vapors disperse with oxygen and nitrogen in normal air. Consequently, hazardous gases will travel with normal air deep into the lungs. Depending on solubility and other properties, a gas may go into solution in the blood or attach to red cells or elements of the blood. The blood transports the material to other tissues in the body for which there may be more affinity.

Consider carbon monoxide. It forms a bond with the hemoglobin of the red cells more readily than oxygen. In addition, because it does not release from the hemoglobin easily, the red cells are unavailable to bond with oxygen. Red cells become ineffective in transporting oxygen throughout the body. Cells normally supplied with oxygen suffer oxygen deficiencies.

Although gases and vapors will move freely with inhaled air, particulates may behave differently. Because of their mass or shape, larger particulates (generally those greater than 5–7 μm in diameter) will not make sharp turns

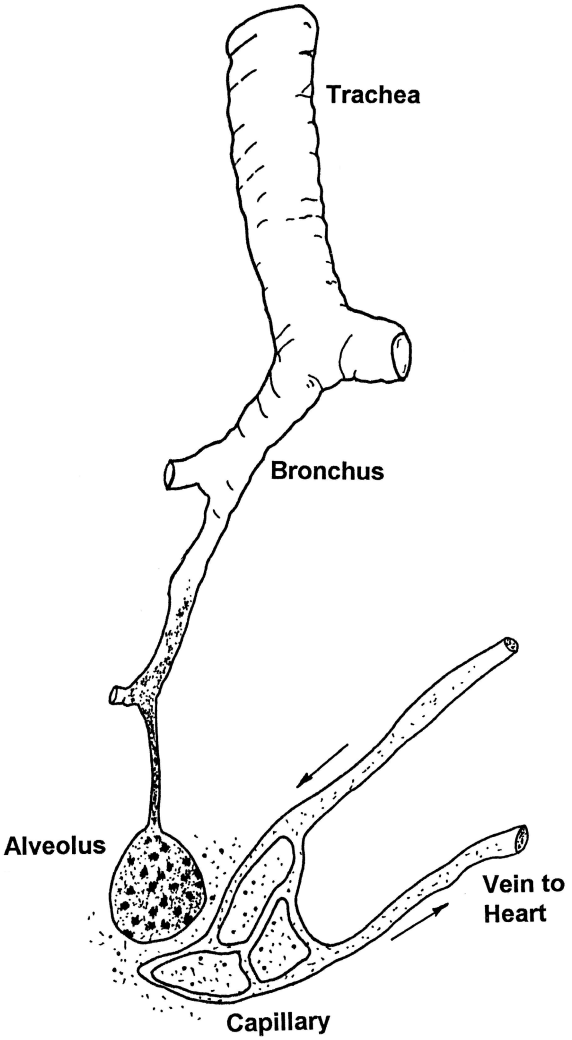


Figure 24-1. General structure of the human respiratory system.

with air movement. They impinge on the mucus membranes of the upper respiratory tract. The cilia, which line the mucus membrane, move the foreign matter upward along the respiratory tract in a cleaning process. A person expectorates or swallows the foreign materials.

Smaller particulates (less than 5–7 μm in diameter) will reach the alveoli. Because particulates smaller than 0.5 μm tend to remain airborne, they pass from the lungs as one exhales. Those between approximately 0.5 and 5–7 μm have a good chance of lodging in the alveoli. Some particulates may become absorbed in the bloodstream. Over time, others may become engulfed by cells in the alveoli.

Ingestion Ingestion involves eating or drinking materials. Ingested materials are absorbed into the blood after traveling to the intestinal tract. Although people ingest little toxic material directly from work environments, food may

become contaminated by hands or from eating areas not well cleaned. Someone may ingest some toxic material originally inhaled and moved through ciliary action to the throat and swallow it.

Absorption through the Skin Some materials enter the bloodstream through the skin. The skin may be abraded or have lesions that foster absorption. Some materials become absorbed through intact skin. Elevated skin temperature or moisture on the skin may enhance cutaneous absorption. Some skin areas, such as the back of the hand and follicle-rich areas, exhibit higher absorption rates than areas like the palm of the hand and the forearms.

Injection Some materials may become injected purposely or accidentally. Accidental injection is more important for occupational settings. Refer to the discussion of injection injuries in Chapter 19.

Direct Contact with Tissue

Beside the three main routes of entry, some materials may be harmful in direct contact with external tissue.

Dermatitis There are many forms of skin disorders. Some result from exposures to chemicals. Dermatitis is a general term for skin disorders. Some forms of dermatitis exhibit reddening. Others involve cracking, sores, acne, and other disorders. Some forms of dermatitis, called contact dermatitis, result from direct contact with a substance in gaseous, liquid, or solid form. The substances may be direct irritants or act as allergens.

Chloracne is a form of dermatitis that results from chlorinated naphthalenes and polyphenyls acting on sebaceous glands in the skin. The acne-like appearance can occur on skin of the hands and arms or other areas of the body.

Eye Irritation Substances may contact eyes or tissues around the eyes and cause irritation or more severe injury. Conjunctivitis is an inflammation of the conjunctiva, the delicate membrane that lines the eyelids and covers the exposed surface of the eyeball.

24-4 SOURCES OF TOXICOLOGICAL DATA

Methods for Assessing Toxicity

Toxicity data for substances come from many sources, most often from controlled studies. Because all chemicals can be toxic, the studies address not only the amount of chemical involved, but also the conditions of exposure. Nearly all substances fail to exhibit effects at very low exposure levels. Effects begin to appear at some level. This suggests a threshold level for effects. Above this level, increased concentrations will create more severe effects. Not everyone exhibits effects at the same exposure level. Often there are individual differences. As exposure levels increase, a larger portion of a population will likely exhibit effects.

Human Experimentation One way to collect data on toxicity of materials is through experimentation with human subjects. In general, society does not condone human experimentation. On occasion and with an acceptable study design, society may accept some human testing of substances for medical treatment. When a pharmaceutical substance appears to have high benefit and relatively little risk as a result of many other tests, the FDA may approve testing in humans. There is virtually no opportunity to perform general testing of substances for toxicity on human subjects. As a result, toxicity data must come from other than human tests.

Human Experience Sometimes accidental exposures provide opportunities to compile data on the toxicity of a substance. The exposures may be acute or chronic. In accidental exposures there is no control over the exposure. The difficulty is knowing what the exposure level was. Researchers must estimate exposure levels and conditions from limited information using epidemiological procedures. Epidemiology is the study of disease in human populations.

After a pattern of effects or disease appears that could be related to some exposure, further testing may result. For example, workers exposed to certain pesticides exhibited similar disease patterns that stimulated further testing. The testing ultimately lowered exposure standards and even led to a ban for certain pesticides.

Animal Studies Most toxicity data come from controlled and replicated animal studies. The physiology of animal species varies from humans. As one moves farther away from humans in the zoological chain, the meaningfulness of test results is less valid. Generalization to humans becomes difficult. Standard tests and methods for rating toxicity help estimate human effects. Controlled breeding and raising of test species also help improve reliability and comparability of results.

Time creates a problem in toxicity testing. Some substances produce disease in a portion of a population after a long latency period or following chronic exposures. To replicate slow exposures or wait for latency periods would be very expensive. As a result, many toxicity test procedures involve high dose rates. The units of measure for controlled doses in experimental animal populations are quantities per unit body weight, per unit of skin area or per unit of volume of inspired air. Toxicity theories assume that the product of the concentration and the time of exposure have a linear

or near linear relationship with the effects. This practice has been the source of much debate.

Studies report toxicity data for animal populations in various units. One unit of measure is lethal concentration (LC), which applies to airborne concentrations. Another unit of measure is lethal dose (LD), which involves ingestion, injection or other means of applying a substance. Reported effects are often the portion of the exposed population that dies as a result of the controlled exposure. A subscript indicates the portion that died. For example. LD_{50} means that 50% of a test population died from a dose. LC_{10} means that 10% died from an inhaled concentration. Another measure is TCL. It is the lowest published lethal concentration in air. Similarly, TDL is the lowest published lethal dose. Other notations in toxicity tables indicate effects on skin, blood, nervous system, muscles, or other tissue and organs. Notations also indicate whether a substance produces particular effects. Examples are irritation, or mutagenic, carcinogenic, teratogenic, or other effects.

Microorganism Testing Because animal testing is expensive and time-consuming, researchers have developed some short-term tests for chemical toxicity. Many of these involve bioassays of microorganisms. Studies monitor the growth patterns of particular bacteria. Some of the bacteria have exposures to the chemical being tested. Another group of bacteria do not have exposures. Researchers compare effects of the two study groups. These tests may help screen substances rapidly for particular characteristics.

The U.S. EPA uses automated chemical screening technologies to expose living cells or isolated proteins to chemicals. The program is called the Toxicity Forecaster (ToxCast™).[21] The screening technologies are high throughput screening technologies. The program has evaluated over 2,000 chemicals for potential toxic effects.

In general, short-term tests have limitations. They do not include variables that animal studies do. It becomes difficult to use mathematical models to extrapolate test results to humans. For example, one of the notable short-term tests for carcinogens is the Ames test. The procedure uses Salmonella and the results involve dose, but not time or duration of exposure. Some people criticize the Ames test for a lack of reliability. The Ames test demonstrates high correlations between certain known carcinogens and human experience. For other carcinogens there are low correlations between test results and human experience.

24-5 CONTROLS

There are three classes of controls for protecting people from exposure to hazardous materials in the workplace:

- engineering controls;
- work practices and administrative controls;
- personal protective equipment.

One should consider these controls in the order presented, as discussed in Chapter 9.

Engineering Controls

Engineering controls include process changes and substitution of nonhazardous substances, enclosing a source, isolation of a worker, and the use of ventilation.

Substitution Replacing a hazardous material with a nonhazardous materials removes the danger of a hazardous material exposure. Replacing a hazardous material with one that is less hazardous may be a desirable substitution. If an alternate material does not perform as well as the original material, substitution may not produce a desirable solution.

Isolation Isolation places a barrier between hazardous contaminants and workers. One possible approach is enclosing the process to contain a hazardous contaminant and prevent worker exposures. An enclosure often has an exhaust ventilation system as part of it.

Glove Box For some enclosures, there are ports with gloves sealed to the ports. A worker uses the gloves to reach inside the sealed enclosure and perform tasks. This type of enclosure is a glove box.

Control Room Another approach is to have an isolated control room. Workers spend most of their time in a room supplied with clean, uncontaminated air. They look through windows to observe an operation that involves hazardous materials. The room encloses the displays and controls needed for the process. The separation prevents potential exposures to contaminants.

If workers must enter the contaminated or hazardous process area, they may need protective clothing and breathing equipment. If workers must enter the hazardous area frequently, a control room may not be the best solution. A problem is making sure workers put on personal protective equipment each time they enter the hazardous area. They may need to go through decontamination before reentering the control room.

Separation Separating hazardous operations from non-hazardous ones is another form of isolation. Workers who must enter the hazardous area must have suitable personal protective equipment. Those who work in the non-hazardous areas may not need personal protective equipment.

Ventilation Ventilation is useful for airborne contaminants. There are two types of ventilation for controlling hazardous substances. One type of ventilation is general ventilation. The second type is local exhaust ventilation. Chapter 25 gives details on ventilation.

General Ventilation In general ventilation one moves fresh outside air into the general work space to dilute or displace contaminants. The goal is to keep concentrations at or below allowable levels. There are several limitations for general ventilation:

- It normally requires movement of large volumes of air.
- The outdoor air may already be contaminated and not fresh or clean.
- Heating. cooling, or dehumidifying outdoor air is costly.
- The general movement may not dilute substances at all locations in a space to keep air quality within limits.

Local Exhaust Ventilation Local exhaust ventilation requires the management of much smaller volumes of air compared to general ventilation. Local exhaust systems capture contaminants at or near their source before hazardous substances reach the breathing zone of people. A system moves the air to locations where people will not be present. To meet air pollution standards, exhausted air may need treatment to remove and collect contaminants.

Work Practices and Administrative Controls

Work practices and administrative controls include housekeeping procedures, materials handling or transfer procedures, leak detection programs, training, modifying the work, personal hygiene, and collaboration of work among work groups. Administrative controls may organize several control procedures into comprehensive safety programs.

Housekeeping Housekeeping activities include removal of dust accumulation and rapid cleanup of spills. It is good practice regularly to remove hazardous dust from floors, walls or other surfaces. Otherwise the material can become airborne and pose greater danger. Removal should avoid dispersing material into the air. Therefore, vacuum cleaning equipment that properly traps the contaminants is best. Sweeping or using compressed air to remove dust from surfaces will cause material to become airborne.

Materials Handling or Transfer Procedures Loading and unloading of materials can cause materials to become airborne. That may expose workers to hazardous levels of the materials. For example, transferring liquid into an empty tank truck or car will displace residual or evolving vapors from the container. Pouring or dumping dusts or dusty materials into open containers or piles may generate a great amount of airborne dust. Transfer operations may require closed transfer systems. Transfer operations may need exhaust systems to capture contaminants at their source and prevent exposures of workers or others.

Another control during materials transfer is use of containers to collect overflow, spills or leaking material. For example, one could place a drip pan under a fill spout for liquid material.

Leak Detection Programs Leak detection may involve visual inspections and automatic sensor devices. It may include scheduled inspections of valves, fittings, piping, and other potential leak sources. Quick repair will minimize potential exposures. Sensor systems for specific materials can determine if a hazardous material becomes airborne and trigger visual or audio alarms. The alarm signals should start corrective action or automatically shut down a process.

Training Proper training of workers and supervisors is necessary to supplement other controls. OSHA and some states right-to-know or hazard communication laws require training for workers. They need to understand the hazards associated with materials they use or encounter on their jobs. They need to know how to protect themselves from those hazards.

Modify the Work One can reduce the exposure of a person by limiting the duration of exposure. One approach is rotating workers in an activity to keep exposures below recognized limits.

Personal Hygiene Personal hygiene involves cleaning skin that becomes contaminated during normal work activity or following a spill or accident. As part of hazard communication information, proper cleaning agents require identification. General soaps, solvents, or waterless hand cleaners may not be sufficient. Some materials need special washing facilities or emergency showers. If there is a possibility of contamination and injury of eyes, there should be emergency eyewash fountains. Workers may need places to change clothes to prevent carrying hazardous materials home or outside a controlled area. Workers may need employer-provided clothing that remains at work. People should not eat or drink in areas where there are toxic materials.

Collaboration Among Work Groups Later chapters will discuss safety management systems. Work associated with hazardous materials must involve a range of management methods to assure safe working conditions and operations.

One consideration involves collaboration among work groups. Often there are several shifts handling the same

operations and equipment. Several work groups may participate together during the same shift. One work group must communicate and plan activities with other work groups. They must discuss hazards and necessary controls. They need to work together on changing conditions or maintenance tasks.

Personal Protective Equipment

A third approach for controlling exposures to hazardous materials involves use of personal protective equipment. Engineering controls and administrative controls may not remove hazards or reduce them to acceptable levels. The hazards may remain in place because other controls are not feasible, too expensive, or ineffective. Routine and infrequent activities both need personal protection equipment planning. Chapter 28 discusses personal protective equipment in more detail.

Some common types of personal protection equipment are eye and face protection for hazardous liquids and respiratory protection for airborne contaminants. Protection for some hazardous materials may involve other clothing, protective creams and lotions for skin. Infrequent activities, such as maintenance or spill cleanup tasks, may require full suits and air supply equipment.

24-6 MEASUREMENT

Measurements will identify exactly what chemicals are present in the air, in water, or as solids. Measurements for chemicals require knowledge of instruments, methods, and procedures. Measurement begins with collecting samples and analyzing them. Analysis will identify a substance. It will provide data on quantity or concentration. Gases and vapors require different collection procedures than particulates. Some measurements find out if a contaminant is present and how concentrations vary over time.

Laboratory measurements use special instruments for highly accurate analysis and field instruments are used for a quick assessment of conditions. Some instruments are attached to workers (personal samplers or dosimeters) to monitor exposures. Some of these dosimeters determine directly if an exposure exceeds the 8-hr TWA. Arrays of sensors, analysis equipment, and alarm systems are managed by computers to provide continuous monitoring for releases. They warn people by triggering evacuation or corrective procedures for equipment. Many of the instruments require regularly scheduled calibration to assure accurate results. There are a wide range of collection procedures and devices. This discussion is a limited review of collection and analysis equipment.

NIOSH publishes procedures for collecting and analyzing hazardous materials samples and analysis procedures appropriate for particular substances.[22] In addition, it has other publications on air sampling. Other organizations, such as ASTM have standards for instrumentation, sampling and analytical procedures. ACGIH has several publications on air sampling and air sampling instruments. With technological changes in instrument design and features, there are also changes in their use and the methods associated with making assessments. Today, many instruments have built-in software. There are computer systems for collecting and monitoring multiple sites.

Sampling for Gases and Vapors

Short- and long-term sampling devices for gases and vapors exist. Short-term samples involve drawing air into an evacuated, contaminant-free container (plastic, glass, or stainless steel). They may involve pumping a sample into an evacuated container or through impregnated filter paper or gas detection tubes. Many sampling procedures use a small hand pump or squeeze bulb. A grab sample is one type of short-term sample.

There are many kinds of glass detection tubes that contain material designed to change color when they react to particular contaminants. This method is called colorimetry. This form of sampling and analysis device gives quick indications of the presence and concentration of substances. The glass tubes are sealed until used. The user breaks the ends off to allow air to pass through the tube and its indicator material. A scale on the tube or the hand pump holder gives a quantitative reading. One must select the proper indicator tube to test for a known or suspected substance.

Continuous or long-term samples require more elaborate equipment. Sample times are typically 15–30 min. Some systems continually sample many ports or sensors to detect if a leak or release of hazardous material occurs. The ports or sensors may be linked to specific locations.

Portable, powered air-sampling pumps draw air through a variety of collecting devices. Calibration ensures the devices accurately measure the volume of air drawn through them. Some collectors contain an adsorbent material (usually charcoal or silica gel) that accumulates the substance. After collection, samples are analyzed in a variety of ways to assess the type and concentration of contaminants.

There is a variety of portable devices that give direct readings of certain gases or vapors, such as oxygen meters, combustible gas meters that indicate the presence of particular flammable gases, and portable infrared analyzers, and gas chromatographs for assessing many different materials.

Chemical Analysis

There are many ways to identify a type of contaminant and to assess concentration. The proper method depends on the

form of the material, type of material, and collection method used.

- Colorimetric methods cause a reactive material to produce a color in proportion to the quantity of a substance present.
- Ion exchange methods separate elements by passing a sample through calibrated columns of eluting agents.
- Gravimetric methods weigh the presence of a substance collected or the product of a reaction.
- Volumetric methods involve reaction with definite volumes of standard solutions or reagents.
- Gas chromatography measures the length of time materials take to pass through a column of detector material.
- X-ray diffraction produces a unique spectrum when a beam of X-rays impinges on a crystalline sample. X-ray fluorescence is a similar technique.
- Spectroscopy involves affecting a sample with carbon arc, infrared radiation, electron beams, or a high temperature flame. Each process produces a spectrum that gives a unique signature for particular materials.

Sampling for Particulates

Particulates may be liquids or solids. Most often air passes through a collection device to obtain a sample of particulates. Collection may involve filtration, impactors, impingers, or other devices for liquids. The method used depends on the information desired and other factors, such as particle mechanics in an airstream.

There is a variety of special filtration devices for air sampling. Impactors involve a sudden change in direction for an airstream. The airborne particulates impact on a surface because they cannot change direction due to their mass. There are single or multistaged impactors. Impingers move air through a small opening, causing materials to impinge on a plate (or the bottom of a collector tube) immersed in a liquid. The particles become trapped. There are various ways to analyze them.

Some other devices are centrifugal separators, electrostatic precipitators, particle sizers, and counters. Centrifugal separators cause air to spin. Because of their mass, the particulates move to the outside of the rotating air column, where they collect. Electrostatic precipitators place a charge on particulates in an airstream passing through the device. The charged particles move to collection surfaces with an opposite charge and lodge there.

Some analysis requires knowing the number of particles per volume of air in a gas stream or the distribution of particles by size. There are several kinds of instruments for obtaining particle size, the number of particulates, or the distribution by size. Some of these instruments can obtain data as air passes through the device.

24-7 NANOTECHNOLOGY

Engineered nanomaterials are materials intentionally produced that have one primary dimension from 1–100 nm. By comparison, a sheet of newspaper is about 100,000 nm thick and a human hair is about 80,000 nm thick. There are more than 25 million nm in an inch. If a marble were a nm, the Earth would be one meter in diameter.

Nanotechnology is quite new and involves many fields of science. Research and development occur in in many laboratories around the world. Nanotechnology includes materials and applications. One definition for nanotechnology is the following:

> The design, characterization, production, and application of structures, devices and systems by controlled manipulation of size and shape at the nanometer scale (atomic, molecular, and macromolecular scale) that produces structures, devices, and systems with at least one novel or superior characteristic or property.

The potential applications for nanotechnology cross electronics, medicine, materials, food, and other fields.[23] Nanotechnology creates challenges for insurance, waste management, safety and health, and management.

Little is yet known about the effects of nanomaterials and exposures for humans and that creates problems for safety and health. There are no established occupational exposure limits in the United States, but some are emerging from manufacturers of nanomaterials and by other countries. NIOSH has developed RELs for titanium dioxide and carbon nanotubes and carbon nano fibers.

Hazards

Knowledge of hazards for nanomaterials is limited. Current studies will produce more short-term, repeated, and long-term exposure information. Since nanomaterials have not been around very long, long-term study results will take a while.

One basis for identifying potential hazards for nanomaterials is the composition of the material itself. Known hazards associated with specific material are likely to apply to the material in nano forms. However, extrapolation from studies on larger sizes to small sizes does not have data to support such interpretations.

Little information exists for respiratory effects of inhaled nanomaterials related to their size. In some cases, the small size allows particles to attach to lung surfaces. In other cases, inhaled nanomaterials may initiate inflammatory responses.

Some nanomaterials tend to aggregate or agglomerate to form larger dimensions. That may be temporary. Little is known about this property and its relationship to hazards.

Early studies established that some nanomaterials accumulate in hair follicles and penetrate the skin, especially if the skin is flexed. The results may not apply to all nanomaterials. Some nanomaterials can penetrate protective materials in personal protective equipment.

Controls

Research, production, and cleaning activities that involve nanomaterials should employ preliminary hazard analysis (PHA) and other analytical procedures to identify controls needed for nanomaterial operations. NIOSH recommends using engineering controls to protect workers. They include removing hazardous conditions and placing barriers between workers and operations and handling activities. An example of a barrier is a glove box. Another is a laboratory fume hood and local exhaust ventilation. A production method involves continuous liner product bagging systems, commonly used in the pharmaceutical industry. Personal protective equipment is not the most desired solution, but may be necessary to create barriers between nanomaterials and humans.

Another important tool is applying prevention through design strategies. That may include limiting inventories of nanomaterials, using fail-safe devices to prevent processes from deviating outside limits, and installing closed transport system to isolate nanomaterials.

There is a need to assess exposures to assure that protections are effective. There is a need for thoroughly implemented safety management systems.

Resources

An important source of information on nanomaterials may be the supplier. In many countries, suppliers must provide Safety Data Sheets on hazardous substances. NIOSH has begun offering guidelines for nanomaterials.[24] OSHA offers recommendations for working with nanomaterials.[25] The United Kingdom, Australia, the EU, and other countries publish guidelines.

24-8 CONFINED SPACES

Confined spaces are those that hinder activities of workers who enter, work inside or exit. Many are enclosures having limited means of access and egress. OSHA classifies confined spaces[26] as simply confined space or permit-required confined space. The latter applies if one or more of the following conditions apply:

- contains or has the potential to contain a hazardous atmosphere;
- contains a material with the potential to engulf someone who enters the space;
- has an internal configuration that might cause an entrant to be entrapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross-section;
- contains any other serious recognized safety or health hazard.

OSHA publishes guidance for permit-required confined spaces.[27]

Examples of confined spaces are storage tanks, tank cars, pressure vessels, boilers, bins, silos, and similar enclosures that have access through a manhole or door. Confined spaces may be open pits, vaults, and vessels with limited ventilation, as well as underground utility tunnels, storm sewers, pipelines, septic tanks, and similar containers. Some partial enclosures, such as a railroad boxcars, are confined spaces.

A long time ago miners sent a canary into a mine before miners entered. If the canary returned, the atmosphere was satisfactory for workers. If the canary did not return, miners assumed the atmosphere was not suitable for workers. Too often workers entered a confined space and become a canary that does not return. Today confined spaces require special procedures to ensure the atmospheres are safe before people enter or work in them.

Hazards

There are three main hazards of confined spaces. They are oxygen deficiency, toxicity, and flammable and combustible gases, vapors, or dusts. There may be other hazards in confined spaces as well.

The first hazard for confined space is oxygen deficiency. Oxygen-deficient atmospheres are those with less than 18% oxygen. This concentration can result from other gases mixed in air that reduce the normal 21% of oxygen in the atmosphere. Another way that oxygen deficiencies arise is the presence of heavier-than-air gases that settle in a closed container, especially where there is no opening at the bottom. Heavier-than-air gases also create problems when there is little ventilation and limited mixing of gases within a confined space. Some confined spaces have oxygen-depleting bacteria. Some have oxidation processes (such as rusting) that consume available oxygen. Combustion consumes oxygen and may reduce required levels for breathing.

The second hazard is toxicity. The toxic materials may have direct effects. An example is pulmonary paralysis from hydrogen sulfide. Toxic materials can be asphyxiants that interrupt oxygen transport. An example is carbon monoxide. Toxic materials may be irritants at very low concentrations and lethal at higher levels, such as eye irritants that reduce vision.

The third hazard of confined spaces involves flammable and combustible gases, vapors, or dusts. Sources of heat

CASE 24-5

24-5a

May 24, 2012, Baltimore County, MD. A farmer, Glenn Nolt, was preparing to pump cow manure into a truck from a 2-million gallon liquid, open-air manure pit. His 18-year-old son, Kelvin, and 14-year-old son, Cleason, were helping with the operation. All three were found dead in the pit. An autopsy established that they died from asphyxiation. The probable cause was death by fast-acting hydrogen sulfide. Family members assumed that the two sons had tried to rescue their father after he was overcome.[a]

24-5b

July 3, 2007, Shenandoah Valley, VA. Five people died in a manure pit at a dairy farm. Reports suggest that the likely cause was methane or hydrogen sulfide gas.[b] Emergency workers assume that the farmer was overcome first. Then his hired man tried to rescue him. Finally the farmer's wife and two children also tried to help. The accident began when the farmer, Scott Showalter, tried to transfer manure from one small pit to a larger pit that measured $20 \times 20 \times 8$ feet deep. The transfer pipe became clogged. The farmer entered the pit to remove the blockage.

[a]http://articles.baltimoresun.com/2012-05-24/news/bs-md-farm-deaths-20120524_1_manure-pit-dairy-farm-liquid-manure

[b]www.washingtonpost.com/wp-dyn/content/article/2007/07/03/AR2007070302136.html

or spark may ignite these materials and an explosion may result. The gases may result from residual fuels, methane produced by decay (anaerobic bacteria), or heavier-than-air vapors that flow into the space.

Another hazard of confined spaces is a pressurized atmosphere. When someone opens a pressurized container, the door may fly open causing injury. Confined spaces may contain moving parts that can cause injury. The moving parts may need to follow lockout and tagout procedures and other procedures that remove or restrain stored energy. There may also be hazards from electrical equipment or dangers from ducts, pipes, or drains that connect to sources of hazardous materials.

Controls

Prior to entry, one must evaluate a confined space for hazards. Based on the assessment, there must be a determination whether the space is a permit-required confined space.

If pressurized, it should be depressurized. Connections to potentially hazardous materials must be isolated and sealed. Energy sources must be locked out and tagged out. Stored energy must be released or controlled to prevent inadvertent release. Someone knowledgeable must test the atmosphere for oxygen content, toxic materials and flammable gases, vapors, and dusts. Atmospheric testing must occur at the entry and other locations because there may be layering of gases or unequal distribution of concentrations.

In many cases, ventilation systems must be set up prior to entry. They must provide adequate breathable air supplies unless workers are going to wear self-contained breathing apparatus. Sometimes elevated oxygen levels are pumped into confined spaces to produce breathable mixtures throughout the space. The ventilation must also reduce flammable hazards to 10% or less of lower flammable limits. The intake for the ventilation system must not take in exhausted contaminants.

If there are to be heated processes, such as open flames, welding and cutting, in a confined space, there is a need to take precautions for fire protection and removal of smoke and fumes. If workers are to use solvents for cleaning, they must be aware of the hazards of the solvents. Precautions must be in place. Electrical equipment should use low voltage.

Activities in a confined space may create noise, ionizing radiation, heat or cold hazards. Planning for work in a confined space must identify and implement necessary precautions.

Workers involved inside confined spaces or in support of confined space activities must be trained in the hazards associated with the operations. They must learn what procedures to follow prior to entry, during occupancy, and in emergencies. They must know rescue procedures. They must know what protective or rescue equipment to have, how to use it, and position it for use.

There should be at least two workers involved in confined space work. One is the worker. The other should be an observer. The observer is the prime rescue person and cannot enter the space without a replacement observer. With proper planning, rescue can be completed without a second person entering the space. Use of lifelines and harnesses or belts is critical.

Prior to beginning work in a confined space, workers should receive entry permits. A confined space permit system requires the identification of the space and an evaluation of the potential hazards. Supervisors and safety specialists must each agree and sign that all pre-entry evaluations and work and rescue preparations were completed and the space is ready for safe entry.

Standards

OSHA has some standards for confined space activities as previously noted (see note 19). The American National Standards Institute has a standard for working in confined spaces.[28] Other countries have standards and guidelines on work in confined spaces.[29]

24-9 PROCESS SAFETY

Process plants produce many commercial products. They use chemical and other operations to produce chemicals, pharmaceuticals, petroleum products, and other materials. Process engineering involves the design, operation, control, and optimization of chemical, physical and biological processes. Process plants may use chemical reactions, heat and thermodynamics, physical conditions and other means to achieve the desired output from raw materials in liquid, solid, or gaseous forms.

Process safety addresses the main hazards of chemicals (fire and explosions, reactivity, toxicity, and corrosivity) during process plant production. Chemical, petroleum, pharmaceutical, and related manufacturing areas are part of the process industry. All apply process safety practices. Occupational safety mainly considers the protection of people. Process safety addresses safety issues for processes themselves. It may also impact personal safety. Case 24-1 and Case 17-5 are examples of process safety failures.

Process safety is a collection of management systems that ensure the safe operation of processes and process plants. It seeks to prevent unintentional releases of chemicals, energy, steam, and other potentially dangerous materials.

The American Society of Chemical Engineers (AIChE) is a technical society devoted to chemical engineering and associated technologies and issues. Many chemical engineers work in the chemical process industry. In 1985, AIChE established the Center for Chemical Process Safety (CCPS).[30] It was an industry response to the Bhopal, India, disaster (Case 24-1). It has become the center of expertise for process safety. It publishes many publications on process safety, and conducts conferences and training to advance process safety practices.

Many process safety practices are combined into a safety management system, recently called Risk Based Process Safety (RBPS). Chapters 34 and 35 will address safety management systems, including RBPS.

The U.S. Chemical Safety Board (CSB)[31] is an agency that investigates industrial chemical accidents. The CSB conducts root cause investigations of chemical accidents at fixed industrial facilities. Root causes are usually deficiencies in safety management systems. However, they can be any factor that would have prevented the accident if that factor had not occurred. Other accident causes often involve equipment failures, human errors, unforeseen chemical reactions, or other hazards. The agency does not issue fines or citations. It makes recommendations to plants and regulatory agencies. The agency publishes reports of investigations that provide insights and lessons learned that are of use to those involved in process safety.

Process Safety Management Standard

OSHA has a standard for process safety.[32] OSHA publishes publications offering guidance for compliance with this standard.[33] The standard differs from most OSHA standards because this standard is performance-oriented rather than being prescriptive. Employers with chemical and other processes falling under the standard must complete a study and produce data and a report focused on ensuring safety processes. For OSHA, the word "process" means any activity involving a highly hazardous chemical including using, storing, manufacturing, handling, or moving each chemical at a site or any combination of those activities. A process includes vessels that could involve release of a highly hazardous chemical.

Process Safety Information The standard requires application of certain steps and methods. The first step is compiling written process safety information. Information on the hazards of a highly hazardous chemical must address toxicity, PELs, physical data, reactivity data, corrosivity data, and thermal and chemical stability data.

Information on the technology of a process must include:

- a block flow diagram or simplified process flow diagram;
- process chemistry;
- the maximum intended inventory;
- the safe upper and lower limits for such items as temperatures, pressures, flows, or compositions;
- an evaluation of the consequences of deviations, including those affecting the safety and health of employees.

Information on the equipment in the process must include:

- materials of construction;
- piping and instrument diagrams;

- electrical classification;
- relief system design and design basis;
- ventilation system design;
- design codes and standards employed;
- material and energy balances for processes built after May 26, 1992;
- safety system, such as interlocks, ventilation, or suppression systems.

The information must document compliance with good engineering practice and existing codes, standards, and practices.

Process Hazard Analysis (PHA)

The next step is completing a thorough, orderly, systematic approach for identifying, evaluating, and controlling the hazards of the processes involving the highly hazardous chemicals. There must be documentation of the priority order used for the analysis. The analysis must use one or more of specified methods to determine the hazards and evaluate them. Several of these methods came from system safety practice, discussed in Chapter 36. OSHA Publication 3133 (Note 33) summarizes each of the methods.

What-If The analysis team develops "what-if" questions to help identify component, process, and procedural errors at all handling and process steps. The team documents the questions and the range of answers.

Checklist This is a more sophisticated method applicable to more complex processes. Team members evaluate the process or parts of it against the checklist. The team completes documentation of responses to checklist items.

What-If/Checklist This is a combination of the first two methods. It provides for a more comprehensive review of hazards of materials, process technology, procedures, equipment design, instrumentation control, incident experience, and previous hazards reviews. It should cover all steps in the process. It may involve a field tour of an operation. The team documents responses to all parts of the methodology.

Hazard and Operability Study (HAZOP) This method is formally structured to systematically investigate each element of a system for any kind of deviation from an intended design that creates hazards and operational problems. It may focus on several specific parameters, such as flow, temperature, pressure, and time. The method identifies safeguards and protections along with failures, causes, and consequences.

Failure Mode and Effects Analysis (FMEA) This is a formal process for studying component failures that could affect operational safety.

Fault Tree Analysis This method uses qualitative and/or quantitative analysis of all undesirable outcomes of a process. It uses a diagrammatic approach to visualize what may go wrong. The method starts with low-level component failures and works upward to higher-level failures. In a quantitative application, probabilities become assigned to failures. The probabilities allow calculations for the likelihood of a higher level failure.

An Appropriate Equivalent Methodology OSHA does not specify what methods are acceptable in this category.

The expertise of the team handling PHA is important. Participants should know about process engineering, process operations, and the methods used. OSHA requires an update of the analysis at least every five years. Employers must retain records of the process information and PHA.

Operating Procedures

A third step involves developing and implementing written operating procedures based on the earlier steps.

Other Steps

The OSHA Process Safety Management standard requires other steps.

Employee Participation Employers must create a written plan of action for employee participation. Employers must consult with employees and their representatives on PHA, and other steps in process safety management.

Training An employer must train employees involved in operating a process in the process and written operating procedures. There must be refresher training for employees at least every three years. There must be documentation verifying completion of training requirements by all employees involved.

Contractor Management Employers must establish details relating to use of contractors for repair, maintenance, and other support for a process. There must be a clear explanation of contractor responsibilities. Employers must share information about hazards of the process.

Pre-Startup Safety Review Employers must plan and conduct detailed pre-startup safety reviews for new processes and for those having undergone changes.

Mechanical Integrity Employers must establish and implement written procedures to maintain the integrity of process equipment. The written procedures must include inspection and testing and identification of excursions for acceptable process limits.

Hot Work Permits Employers must implement a hot work permit procedures before any kind of hot work begins.

Management of Change Employers must plan for process changes, including development of written change management activities. Many tasks are defined in the above steps.

Incident Investigation PSM must include investigation of all incidents that resulted in or could have resulted in a catastrophic release of a highly hazardous chemical in the workplace. The standard requires documented incident reports.

Emergency Planning and Response There must be emergency pre-planning and training of all employees who may respond to an incident. The planning must include details relating to waste and other regulations.

Compliance Audits Employers must certify compliance with all aspects of the PSM standard at least every three years. There must be a report of findings by the audit team.

EXERCISES

1. A worker is exposed to naphthalene on the job for an 8-hr shift.
- **(a)** What is the OSHA PEL?
- **(b)** What is the NIOSH REL?
- **(c)** What is the NIOSH STEL?
- **(d)** Is there any danger of absorbing the material through the skin?

2. A worker is exposed to silica dust (crystalline quartz).
- **(a)** What is the OSHA PEL?
- **(b)** What is the NIOSH REL?

3. During an 8-hr day, workers in one plant are exposed to a mixture of three chemical vapors considered to have additive effects:
- **(a)** nitrobenzene 0.3 ppm
- **(b)** ethyl acetate 100 ppm
- **(c)** 2-butanone 75 ppm

Has the OSHA exposure standard for the mixture been exceeded?

4. A city has an infestation of mosquitos. There is a public fear of meningitis. Citizens demand that the city take some remedial action. A city worker sprays neighborhoods with malathion mixed with kerosene. Explain what dangers may exist for the worker. Explain any exposure limits.

5. A worker in a pharmaceutical plant helps produce iodine.
- **(a)** What is the OSHA PEL?
- **(b)** Are there any special considerations for the worker's exposure?

6. Locate an organization that has activities involving confined space entry. After reviewing the OSHA confined space entry standard, develop a written procedure for:
- **(a)** a permit required for confined space
- **(b)** a confined space for which a permit is not required

REVIEW QUESTIONS

1. Approximately how many chemical compounds are there? How many have economic value? How many have published exposure standards?

2. What federal agency regulates the use of chemicals related to the following?:
- **(a)** outdoor air quality
- **(b)** water quality
- **(c)** public transportation
- **(d)** the workplace
- **(e)** indoor air quality
- **(f)** consumer products

3. What do the following Acts address or what significant elements do they cover?
- **(a)** Clean Air Act of 1970 and 1977
- **(b)** Clean Water Act of 1972
- **(c)** Safe Drinking Water Act of 1974
- **(d)** Federal Water Pollution Control Act of 1977
- **(e)** Marine Protection, Research and Sanctuary Act of 1972
- **(f)** Federal Insecticide, Fungicide and Rodenticide Act of 1972
- **(g)** Resource Conservation and Recovery Act of 1976
- **(h)** Toxic Substances Control Act of 1976
- **(i)** Hazardous Materials Transportation Act of 1974
- **(j)** Comprehensive Environmental Response, Compensation and Liability Act of 1980
- **(k)** Superfund Amendments and Reauthorization Act of 1986
- **(l)** Emergency Planning and Community Right-to-Know Act of 1986

4. What are the three major hazard categories for chemicals?
5. What two major forms do airborne contaminants take?
6. Define the following:
   (a) dusts
   (b) fumes
   (c) smoke
   (d) aerosols
   (e) mists
   (f) gases
   (g) vapors
7. What is a latency period for a health effect?
8. Compare acute and chronic exposures.
9. What is the difference between local and systemic effects from chemicals?
10. What is an asphyxiant?
11. What is a nuisance dust?
12. What are some individual differences among people who are exposed to chemicals?
13. What are the following?
   (a) pneumoconiosis
   (b) carcinogen
   (c) mutagen
   (d) teratogen
   (e) dermatitis
   (f) chloracne
   (g) conjunctivitis
14. What are the three main routes of entry into the body for chemicals?
15. Name and briefly explain four methods for assessing toxic properties of chemicals.
16. Explain the following:
   (a) LD_{50}
   (b) LC_{10}
   (c) TCL
   (d) TDL
17. Define the following related to chemical exposure standards:
   (a) PEL
   (b) REL
   (c) STEL
   (d) TWA
   (e) TLV
   (f) "skin" notation
   (g) ceiling value
   (h) BEI
18. Name and briefly explain three engineering controls for chemicals.
19. Name and briefly explain six work practices and administrative approaches for controlling exposures to chemicals.
20. Why is personal protective equipment a last choice method for controlling exposures to chemicals?
21. Briefly explain the following:
   (a) grab sample
   (b) colorimetry
   (c) long-term sampling for gases and vapors
   (d) impinger
   (e) centrifugal separator
   (f) electrostatic precipitator
22. What size characterizes nanomaterials?
23. What are the known hazards unique to nanomaterials?
24. What are the following?
   (a) confined space
   (b) permit-required confined space
25. What are the main hazards of confined spaces?
26. How should work teams be set up for confined spaces? Explain the reasoning.
27. What is process safety?
28. What are the main elements of the OSHA Process Safety Management Standard?
29. Explain PHA.

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CHAPTER 25

VENTILATION

25-1 TYPES OF VENTILATION

There are several types of ventilation and each has different uses. Several of the previous chapters have discussed the need for ventilation. Chapter 16 identified the need for ventilation to keep flammable gases and vapors below the lower flammable limit (LFL). Chapter 18 discussed the role of air movement in reducing heat stress. Chapter 24 identified a requirement to keep toxic contaminants at or below certain concentrations and removing contaminants to prevent worker exposures. Chapter 24 noted the importance of ventilation in making confined spaces safe for entry.

Ventilation can reduce odors in a room and dilute cigarette smoke. Older air quality standards found in building codes have their origin in studies of acceptable levels of body odor and cigarette smoke.[1] Ventilation can control microorganisms, dusts, and other particulates in hospitals and clean rooms. Some clean rooms use laminar flow to prevent the distribution of particulates in the room.

There is also a need to use ventilation to limit carbon dioxide buildup in a closed, occupied space. During breathing, people inspire air containing oxygen and expire carbon dioxide as a product of cellular combustion. A person expires about 0.7 ft^3 of CO_2 per hour. If the standard CO_2 content of air is 0.03% and the upper limit is 0.6%, then the dilution ventilation air required is 4 ft^3/min per person. This amount is very small. Infiltration in a building usually provides enough air to meet this requirement.

Thermal Control Ventilation

One will recall from Equations 18-2 and 18-4 that air velocity is one of the key physical parameters contributing to control of heat stress. Air velocity strongly influences convective and evaporative cooling. When it is warm indoors and cool outdoors, we may open a window in a building to let in clean air. Not only is there a temperature difference, but there is air movement. We turn on a fan or set a fan in a window to increase air velocity. Most often we use thermal comfort ventilation to provide cooling. However, if the conditions are right, ventilation can warm a space and its occupants.

General or Dilution Ventilation

General ventilation and dilution ventilation are the same. They refer to the process of using clean air (often outside air) to reduce the level or concentration of contaminants in a building or space. Contaminants may be gases, vapors, or particulates.

Dilution ventilation helps reduce concentrations of flammable or combustible gases and vapors below the LFL. When used for this purpose, a common practice is applying a factor of safety to the air requirement, because distributions of concentrations are not always uniform. The rate of contaminant generation or release may vary. The gases or vapors may be lighter or heavier than air and tend to concentrate near a ceiling or floor. Factors of safety range from 3 to 10. High values apply to those contaminants with high toxic or flammable hazards, whereas low values apply to those contaminants with low toxic or flammable hazards.

There are practical limits to dilution ventilation. They include cost, effectiveness, and risk. If there is a high rate of contaminant generation, there is a need for a lot of clean air. The air volume must keep the contaminant at or below the LFL or below some allowable toxic concentration. The cost for energy to move large quantities of air continuously can be high. It is even more expensive to heat, cool, or remove moisture from entering air.

There are other issues with general ventilation. General ventilation does not always reach local sites in a space where concentrations may exceed safe levels for fire or health. Often distribution of air is uneven in a space.

General ventilation may add to problems needing resolution. General ventilation may move contaminated air to uncontaminated locations. It could expose more people by moving toxic mixtures into their breathing zones.

Liquid contaminants may evaporate at varying rates due to variations in process temperatures or varying activities. General ventilation works best where contaminant generation is uniform and the rate of generation is low.

If contaminants are highly toxic or very flammable, then dilution ventilation is not a good choice for contaminant control. Failure to keep concentrations below limits at all

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 25-1

Employees began cleaning a sizeable confined space inside a ship with solvents. The foreman told them to ventilate the space and dilute any vapors with an air hose.

One worker brought in an oxygen hose to ventilate the space and let it run for three hours.

Later, a second worker entered the space smoking a cigarette. He threw the cigarette to the deck. It began to burn. He started to stomp it out with his shoe. His shoe and pant leg caught on fire. The oxygen-enriched space caused the fire to spread rapidly over his clothes. The worker died from the burns.[a,b]

[a]Transcript: www.osha.gov/video/shipyard_accidents/shipyard_accidents_video_transcript.html#v1_4 (Accident Examination 4);

[b]Video: www.osha.gov/video/shipyard_accidents/04_confined_space.html

CASE 25-2

September 17, 2014. Champaign, IL. The Illinois Secretary of State closed its drivers license facility in Champaign until establishing a new facility.

There had been many employee complaints about the indoor environment. Complaints included headaches, sore throats, burning eyes, and a metallic taste. Air quality tests showed that when the facility was unoccupied there were no problems. When the building became crowded with customers, tests showed unusually high levels of carbon dioxide.

locations can have serious consequences. A system failure could produce very dangerous conditions. Local concentrations could exceed limits and lead to injury, fire, or explosion. Someone could interfere with planned circulation and air flow patterns and produce a dangerous condition. For example, someone could stack supplies near a work station that would restrict air movement and prevent dilution. That could cause local workstation conditions to exceed limits.

Principles There are several principles for dilution ventilation arrangements. Contaminated air should move away from occupants. Fresh air should pass by occupied areas first as it moves toward a source of contaminants. Ventilation systems should disperse supplied air to ensure all areas of a space receive fresh air. Supplied air should reduce the possibility of local concentration buildup. There should be places for contaminated air to exit the ventilated space.

Units of Measure Units of measure for dilution ventilation are volume units of air flow. One measure is cubic feet per minute. Air changes per hour are not a good measure, because those reflect room volume only. This does not reflect the rate of contamination reduction. Dilution ventilation requirements are the amount of clean air required relative to the amount and rate of contaminant generated. Computation of ventilation required should adjust air data to standard temperature (0 °C) and pressure (460 mm Hg). The volume of air varies somewhat with atmospheric conditions.

Steady State Concentrations One can compute the dilution ventilation air V_r required to keep some evaporating solvent below a prescribed limit (LFL or TLV) from

$$V_r = \frac{403 \times \text{specific gravity} \times 10^6 \times E \times K}{\text{molecular weight} \times L} \qquad (25\text{-}1)$$

CASE 25-3

Not everyone understands the basic principles of dilution or exhaust ventilation. Instructions must be clear for users and workers.

A can of solvent-based paint included an instruction: “Use with adequate ventilation.” The solvent was toxic.

A worker using the paint placed a window fan on the floor of the closed room where the paint was in use. He turned the fan on high. The fan did not dilute the concentration of solvent that continued to evaporate. The fan distributed the vapors thoroughly in the room. Eventually, the solvent overcame the worker and he passed out.

where

V is in ft^3/min
E is the constant evaporation rate in pints/hr
K is a safety factor (normally from 3 to 10)
L is the limiting concentration (LFL or TLV) in parts per million

and the specific gravity and molecular weight are properties of the solvent.

If the evaporation rate E is in pounds per minute, the coefficient in Equation (25-1) is 387 instead of 403.

Example 25-1 Suppose workers apply adhesive in a certain operation. The adhesive has a solvent base, methyl ethyl ketone (MEK). If the process allows 6 pints of MEK to evaporate per hour, how much dilution air will prevent combustion? The molecular weight of MEK is 72. The specific gravity of MEK is 0.8. The LFL is 1.8. This is a low concentration and therefore quite flammable. As a result, select a high value (8) for a factor of safety. From Equation (25-1), we find that the required dilution air is

$$V_r = \frac{403(0.8)(10^6)(6)(8)}{72(1.8 \times 10^4)} = 11.940\ ft^3/min$$

Concentration Buildup Suppose a contaminant evaporates at some rate in a space that initially contains clean air. Also suppose there is a fixed rate of dilution air for the space. The concentration of the contaminant in the space may increase with time. One can determine what the concentration is after a specific period from

$$\ln \frac{\{G - (Q/K)C\}}{G} = \frac{-(Q/K)t}{V} \qquad (25\text{-}2a)$$

or

$$\frac{G - (Q/K)C}{G} = e^{-(Q/K)t/V} \qquad (25\text{-}2b)$$

where

C is the concentration of gas or vapor at time t
G is the rate of generation of the contaminant
Q is the rate of ventilation
K is the factor of safety to allow for incomplete mixing
V is the volume of the room or space

Example 25-2 A process of degreasing metal furniture begins an operation. Initially, the air in the 20,000 ft^3 dryer is free of solvent vapors. The ventilation rate in the dryer is 2,500 ft^3/min and there is a factor of safety $K = 4$. The degreasing solvent evaporates at a rate 0.8 ft^3/min. How long will it take for the concentration to reach 500 ppm?

One can rearrange and apply Equation (25-2a) to determine the time from no solvent to a concentration of 500 ppm:

$$\begin{aligned} t &= -VK/Q\{\ln[(G - (Q/K)C)/G]\} \\ &= -20,000(4)/2500 \\ &\quad \times\{\ln[(0.8 - (2500/4)(500 \times 10^{-6}))/0.8]\} \\ &= 15.85\ min \end{aligned}$$

Example 25-3 For the process in Example 25-2, what is the concentration after 1 hr?

Rearranging Equation (25-2b), the concentration is

$$\begin{aligned} C &= \frac{G - Ge^{-(Q/K)t/V}}{Q/K} \\ &= \frac{0.8 - 0.8e^{[-(2500/4)(60)/20,000]}}{2500/4} \\ &= 1,084\ ppm \end{aligned}$$

Purging If the contaminants have reached a concentration level and then someone activates dilution ventilation, the concentration will decrease. The rate of purging is

$$\ln(C_2/C_1) = \frac{-Q(t_2 - t_1)}{VK} \qquad (25\text{-}3)$$

where

C_1 is the initial concentration at the time ventilation starts t_1
C_2 is the concentration achieved after time t_2

Example 25-4 For the dryer in Example 25-2, assume that the degreasing line stops. No more furniture enters the dryer. The generation of contaminants stops. At that time, t_1, the concentration in the dryer is 50 ppm. If the ventilation continues, how long will it take to reduce the concentration in the dryer to 10 ppm?

Applying Equation (25-3),

$$\begin{aligned} (t_2 - t_1) &= -KV/Q \times \ln(C_1/C_2) \\ &= -(4)(20,000)/2500 \times \ln(50/10) \\ &= 51.5\ min \end{aligned}$$

Local Exhaust

The main purpose of local exhaust ventilation is to capture contaminants at their source before they contaminate a room or work station. An exhaust ventilation system captures contaminants and moves the contaminated air through ducts to another location. It may be necessary to remove the contaminants before dumping the air outdoors or before recirculating the air. Figure 25-1 illustrates the key components in a local exhaust ventilation system. Later sections of this chapter give more details about local exhaust ventilation systems.

CASE 25-4

November 15, 2014, Laporte, TX. Some 23,000 lbs of methyl mercaptan were released at the DuPont chemical plant. The plant produced insecticide and fungicide products.

According to preliminary reports, the plant experienced an unplanned shutdown of the methomyl unit because water inadvertently had diluted a chemical storage tank several days earlier. The restart process was underway when the problems occurred. One problem was a plugged supply pipe leading from the methyl mercatan storage tank. The chemical entered a process vent system inside the building. Workers opened a valve used to drain liquid from the vent system to release pressure. The valve drained directly into the work area inside the building. *The ventilation fans inside the building were not in service*. While performing these activities, personnel were not wearing personal protective equipment that should have included supplied air respirators.

Four workers died of the exposure. A fifth received injuries.[a,b]

[a]www.csb.gov/assets/1/16/December_11th_hearing_Final.pdf

[b]www.csb.gov/advisory-update-on-csb-investigation-into-fatal-dupont-accident-in-laporte-texas-that-killed-four-workers/

One advantage of local exhaust ventilation is complete or nearly complete capture of contaminants. The capture is independent of the rate of contaminant generation, toxicity, flammability, or the type of contaminant. Another advantage of local exhaust ventilation is the relatively low volume of air required compared to dilution ventilation.

Disadvantages of local exhaust ventilation systems are complexity of design, system cost, and difficulty in modifying or moving the systems. Failures of both dilution ventilation and local exhaust ventilation systems could create dangerous conditions. Local exhaust systems handle toxic contaminants very well. Exhaust systems should have alarms to alert people when there is an interruption of air flow. The alarms help people to respond. They can begin emergency procedures and wear personal protective clothing.

Clean Rooms

Clean rooms are rooms used for manufacturing or research work that requires workspaces that have very low levels of dust, airborne microbes, particulates, or vapors. A ventilation system continually provides clean air to the room. The ventilation system operates upstream of the room. Workers may wear protective clothing to prevent any clothing fibers or hair from contaminating the space. They enter and exit through airlocks to prevent contaminants from entering the room.

Clean rooms allow air to move horizontally or vertically, depending on design. In horizontal design, air enters across an entire wall and exits through the entire wall across the room. Vertical designs move air from an entire ceiling to exit through the entire floor. In vertical design, air movement flows in the direction of gravity. Usually, the air movement is

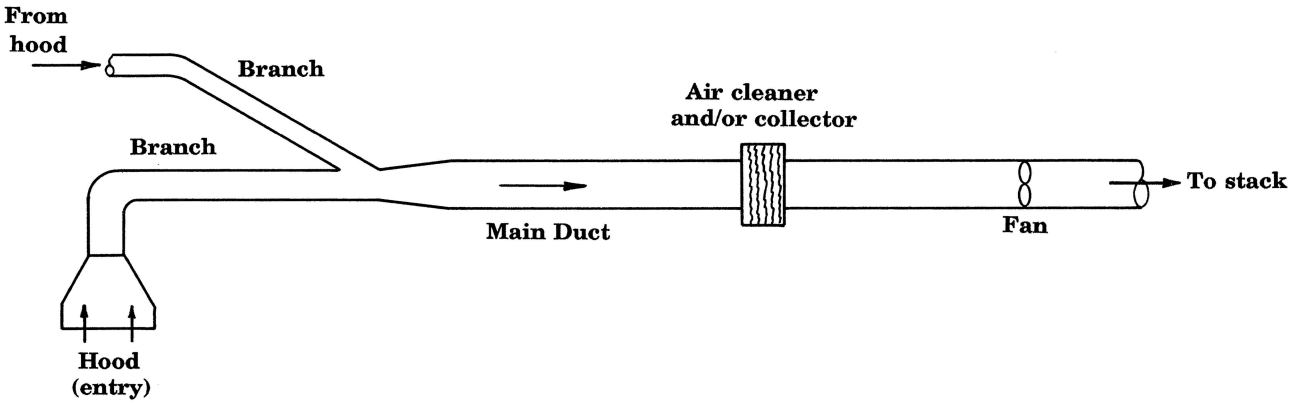


Figure 25-1. Key components of a local exhaust system. If a local exhaust system is used to exhaust toxic contaminants, an alarm may be important to alert people when there is an interruption of air flow.

laminar, low velocities that prevent eddying and mixing that might cause contaminants to become airborne.

Ventilation systems for clean rooms incorporate high efficiency particulate filters (HEPA) and other filtering methods to reduce contaminants to very low levels.

25-2 PRINCIPLES OF VENTILATION

Air Flow

Air moves when there is a pressure difference between two locations. The air moves from the high pressure location to the low pressure one.

Air Flow Quantity The quantity of air flow Q is

$$Q = VA \tag{25-4}$$

where

Q is cubic feet per minute

V is the velocity in feet per minute

A is the cross-sectional area through which air flows in square feet

This is a restatement of Equation 10-6 and principles related to it.

For a pipe or duct of constant cross-sectional area, the velocity of air moving through it is constant over its entire length. If the cross-sectional area changes over the length of a pipe, the velocity is different at each different area of the pipe. The amount of air flowing is constant over the length of a pipe, regardless of cross-sectional changes.

Air Pressure The pressure creating air movement is the total pressure TP. Total pressure has two components: static pressure (SP) and velocity pressure (VP). All three pressures in air flow have inches of water as a measure. The three pressures are related:

$$TP = SP + VP \tag{25-5}$$

Figure 25-2 illustrates the measurement of the three pressures.

Static pressure is the potential pressure exerted in all directions by a fluid at rest. In a duct, static pressure tends to expand or collapse a pipe, depending on whether static pressure is positive or negative. One measures static pressure in a duct normal to the direction of air flow.

Velocity pressure is the kinetic pressure that causes a fluid to flow at some velocity. It is always positive and acts in the direction of air flow. It exists only when air is in motion.

The velocity pressure is related to air velocity as follows:

$$V = 4005(VP)^{1/2} \tag{25-6}$$

where

V is in feet per minute

VP is in inches of water

Pressure Losses in Ventilation Systems

When air moves in a pipe or duct, there are pressure losses because some of the energy involved in potential flow converts to heat. There are several types of losses, each resulting from different phenomena.

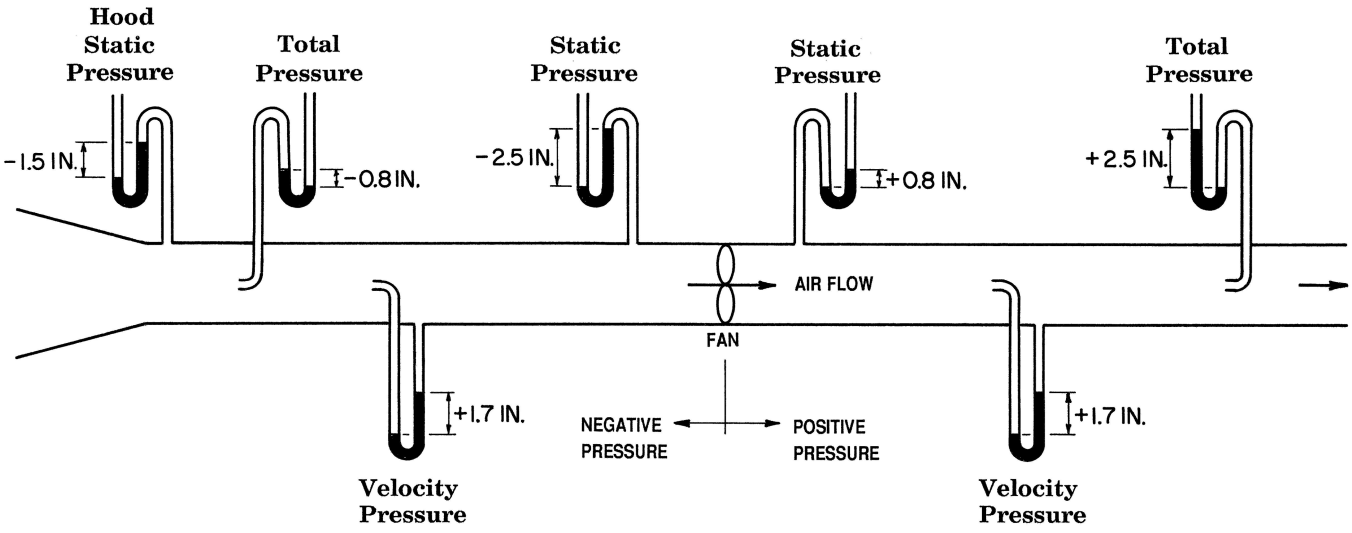


Figure 25-2. Relationships among total pressure, static pressure and velocity pressure.

Friction Loss One type of loss is friction loss (FL). As air moves through a pipe, the pipe surfaces create some friction. The rougher a surface, the greater the friction loss. The higher the air velocity, the greater the friction loss. Friction loss in a pipe or duct varies directly with pipe length, inversely with pipe diameter and directly with the square of the velocity. Friction losses are often given in units of pipe length.

Dynamic Loss Another kind of loss is dynamic loss (DL). Turbulence results when there is a bend in a pipe or the cross-section changes. Dynamic losses increase with increasing abruptness of the bend or change. A unit of measure for dynamic losses is units of equivalent pipe length. For example, a bend or transition (change in pipe diameter) has the same loss as that resulting from friction loss over some length of pipe or duct of the same size. Some report dynamic losses as a fraction of the velocity pressure. For example, a loss for an elbow might be $0.13VP$.

Dynamic losses also result from acceleration of air at rest. Most often this occurs at the entrance into an exhaust system. Turbulence at the entry to the system adds to dynamic losses. The coefficient of entry C_e is a measure of the efficiency at the entry of a hood or pipe. The efficiency indicates how well static pressure converts to velocity pressure.

Other Losses Not only are there friction losses along pipe walls and dynamic losses at the system entry and at each bend or transition, but there are also losses at filters or other air cleaning devices that are part of the system. Filters placed in the air stream will want to slow the flow and create a friction loss. In summary, Bernoulli's equation (Equation 10-8) applies to air flow in ducts. A related form for the equation is the sum of the static pressure and velocity pressure of a point upstream in a ventilation system is equal to the sum of the static pressure, the velocity pressure, friction loss (FL), and dynamic losses (DL) at a point downstream in the system:

$$SP_1 + VP_1 = SP_2 + VP_2 + FL + DL \qquad (25\text{-}7)$$

A ventilation system must expend energy to create a pressure difference between the ends of the system. A fan normally creates the pressure difference for an exhaust system by creating a static pressure great enough to overcome the resistance of the system.

Flow of Jets

A jet of air blown from a small pipe into a large volume of still air can penetrate deeply into the large space. If the velocity of the air jet is V as it leaves a pipe of diameter d, the velocity at a distance $30d$ from the face of the pipe is about $0.1V$. See Figure 25-3.

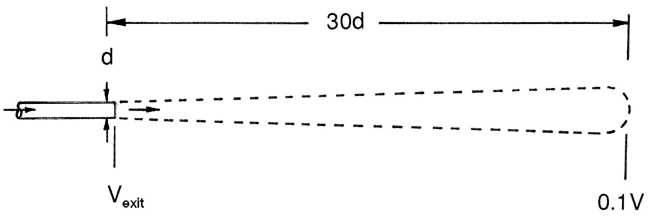


Figure 25-3. A jet of air can penetrate deeply into a space. Air exiting a pipe has approximately 10% of the exit velocity at a distance of $30d$ from the exit.

Flow at Pipe Entry

If the flow involves air being drawn into a pipe of diameter d with a velocity of V at the pipe face, the velocity of air drops off rapidly as a function of distance upstream from the pipe face. For a plain pipe, the velocity at a distance of $1d$ from the pipe face is less than $0.075V$. See Figure 25-4. Placing a flange around the pipe entrance extends the velocity profile only a small amount.

Make Up Air

Regardless of the purpose for ventilation, the air used in ventilation must come from somewhere. Make up air replaces air removed by a ventilation system. If the volume of make up air is less than the volume of exhausted air for a given space, there will be a negative pressure in the space. Conversely, if the volume of make up air is greater than the volume of exhausted air in a space, there will be a slight positive pressure.

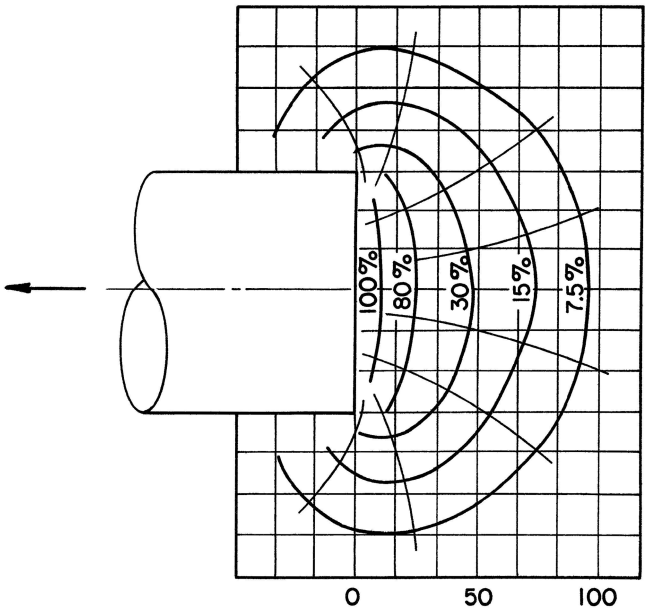


Figure 25-4. The velocity of air entering a pipe or hood decreases rapidly with distance from the pipe entrance.

In general, it is desirable to have a negative pressure in a contaminated space or in a space where there is a source of contaminants. The negative pressure will draw air from adjacent spaces through cracks in windows, doors, ducts, or pipes and the contaminants will stay in the contaminated space. If there are contaminants in adjacent spaces, tight seals between spaces will prevent transfer of the contaminants between spaces. The presence of a positive pressure in a contaminated space will spread contaminated air to adjacent spaces through openings.

Cleaning Air

When a ventilation system removes air from a space through dilution or local exhaust, the contaminants go elsewhere with the removed air, usually outdoors. Outdoor air quality standards limit the dumping of contaminants. As a result, it is common to clean the contaminants from the exhausted air. Some contaminants collected by local exhaust systems may have economic value. There are several types of equipment for removing airborne particulates and gases or vapors from exhausted air. See Section 25-6.

Recirculating Air

Because it is expensive to heat, cool, or remove moisture from ventilation air, it may be more economical to clean exhausted air and recirculate it. When deciding to recirculate air, one must consider the possible effects of recirculation on occupants. If contaminated air has potential health consequences, typically recirculation is not recommended. This is true even if the cleaning process adequately removes contaminants. The more dangerous a contaminant, the more care one should take in deciding on recirculation. Failures in the system and inadequate maintenance can lead to hazardous conditions. The more dangerous a contaminant, the greater the protection needed to ensure that system failures will not circulate hazardous air into occupied areas.

If exhausted air becomes recirculated and there is a health hazard from a potential failure in the cleaning process, there are several design factors to meet. The list below summarizes some considerations.

1. Contaminants in the recirculated air should not exceed recommended concentrations. One can estimate the permissible concentration C_r of a contaminant in air exiting a cleaning device prior to mixing with air in a workspace from

$$C_r = 0.5(TLV - C_o)(Q_T/Q_R)(1/K) \qquad (25\text{-}8)$$

where

C_o is the concentration of contaminant in a worker's breathing zone when discharging local exhaust to the outdoors

Q_T is the total ventilation flow through the affected space (cubic feet per minute)

Q_R is the recirculated air flow (cubic feet per minute)

K is a factor of safety related to incomplete mixing (general range is 3 to 10)

TLV is the threshold limit value of the concentration

2. For recirculation of nuisance contaminants, the applicable coefficient in Equation (25-8) is 0.9 instead of 0.5.
3. There must be a primary and secondary cleaning system in series, each with equal efficiency. An alternative to a secondary cleaning system is a fail-safe monitoring system that monitors the level of contaminants in the recirculated, cleaned air.
4. There must be a warning system that indicates problems in the cleaning systems. A problem may be inefficiency or failure of the secondary system or excessive levels of contaminants exiting the system.
5. If the warning system indicates a problem, either there is a need to divert recirculated air immediately to the outdoors or someone must shut down the contaminant generating process.
6. Periodic or continuous testing of recirculated air is necessary to ensure that the system is working properly.
7. Warning signs must tell occupants of the potential danger from a failure of the recirculation system. It must explain the meaning of a warning signal and the actions required for protection.
8. Occupants may need emergency breathing equipment to wear while exiting the space to a safe location.

AGCIH[2] gives additional factors to consider in designing recirculation systems.

Location of Exhaust Vents and Inlets

Frequently exhaust vents for local exhaust systems end at building roof locations. Also on roofs there are inlets for air conditioning and recirculation systems. When inlet and exit vents are close to each other and when wind conditions are just right, exhausted contaminants may travel directly to inlets and return to the building interior. There should be adequate separation of exhaust vents both vertically and horizontally from any type of air inlet to ensure that contaminants do not reenter the building.

Protecting the Breathing Zone

A basic concept for design of any type of ventilation system is protection of the breathing zone of occupants. Air flow patterns must move contaminated air away from a breathing

zone, not toward or through a breathing zone. If air does move through a breathing zone, it should be clean air.

25-3 CAPTURING PARTICULATES AND GASES

Flow Requirements for Capture

The main idea of local exhaust ventilation is capturing contaminants at their source and removing them.

Capture Efficiency One can accomplish this most easily by enclosing the source as much as possible. Enclosures increase the efficiency of capture, reduce operating costs, and require less air flow to capture contaminants. If there is no way to enclose a source of contamination, the entry (hood) to the local exhaust system should be as close to the source as possible. The farther a hood is from the source of contaminants, the lower the efficiency. Air volume required to accomplish capture increases with distance between a contaminant source and the face of a hood. The shape of a hood can also affect the likelihood of capture. The profile of air movement at the entry extends farther in front of a hood for certain types of hoods compared to others.

Overcoming Other Forces The force created by moving air must overcome other forces acting on contaminants. For gases, vapors, and particulates, the forces include thermal air currents, room air currents, and motion created by a process or operator. Diffusion, buoyancy, and gravity apply to gases and vapors. Buoyancy acts on gases lighter than air and gravity acts on gases heavier than air. Both buoyancy and gravity produce small forces on gases and vapors compared to other sources. Depending on their size and mass, particulates may act differently from gases and vapors. Very small particulates have little mass, act much like gases and remain entrained in air. Large particulates settle out of air due to gravity. Forces from processes that place particulates in motion, such as grinding, may make it difficult to overcome the particle momentum with air movement. Capture is more effective if the motion from a process is in the same direction as air movement for capture.

Capture Velocity The velocity of air required to capture contaminants varies with contaminant and process. Table 25-1 lists a range of capture velocities. Capture velocity is the air velocity at any point in front of a hood necessary to capture a contaminant. Capture velocity must cause contaminants to flow into the hood opening. Capture velocity must overcome opposing air currents and other forces acting on contaminants.

Types of Hoods and Hood Properties

Hoods can have plain openings of a round or square pipe. Hoods may have flanges around their edges, have very narrow slots, and enclose a process. Some hoods form a canopy over a tank or process. For most, the air velocity at some distance in front of the hood is a function of the shape and air flow. Table 25-2 lists properties of various hood types. Slots (small aspect ratio openings) help to distribute uniformly the velocity of air in front of a larger hood face. The face velocity is the air velocity at the hood opening.

TABLE 25-1 Range of Capture Velocities[a]

Condition of Dispersion	Examples	Capture Velocity of Contaminant (Ft/min)
Released with practically no velocity into quiet air	Evaporation from tanks; 50–100 degreasing, etc.	
Released at low velocity into moderately still air	Spray booths; intermittent container filling; low speed conveyor transfers; welding; plating; pickling	100–200
Active generation into zone of rapid air motion	Spray painting in shallow booths; barrel filling; conveyor loading; crushers	200–500
Released at high initial velocity into zone	Grinding; abrasive blasting	500–2000

In each category above, the list shows a range of capture velocity. The proper choice of values depends on several factors:

Lower End of Range	Upper End of Range
1. Room air currents minimal or favorable to capture	1. Disturbing room air current
2. Contaminants of low toxicity or of nuisance value only	2. Contaminants of high toxicity
3. Intermittent, low production	3. High production, heavy use
4. Large hood, large air mass in motion	4. Small hood, local control only

[a]*Industrial Ventilation*, 28th ed., American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 2013.

TABLE 25-2 Properties of Various Hood Types[a,b]

Type	Aspect Ratio (W/L)	Air Volume	C_e
Plain opening: square, rectangular and round	≥ 0.2	$Q = V(10x^2 + A)$	0.72
Flanged opening: square, rectangular and round	≥ 0.2	$Q = 0.75\,V(10X^2 + A)$	0.82
Slot (rectangular)	< 0.2	$Q = 3.7\,LVX$	
Flanged slot (rectangular)	< 0.2	$Q = 2.8\,LVX$	
Booth	To suit work	$Q = VA = VWL$	
Canopy	To suit work	$Q = 1.4PDV$	

[a]From *Industrial Ventilation*, 28th ed., American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 2013.
[b]W = width of rectangular opening, ft; L = length of rectangular opening, ft; C_e = entry coefficient; X = distance in front of hood face, ft; A = cross sectional area, ft^2; P = perimeter of work or tank, ft; D = height above work or tank to canopy face, ft.

Example 25-5 A flanged opening rectangular hood ($W = 4$ in. and $L = 16$ in.) is placed 6 in. from a contaminant source. The process releases the contaminant at low velocity into moderately still air.

(a) What volume of air is required to capture the contaminant?

(b) If the opening dimensions were $W = 2$ in. and $L = 32$ in., what volume of air would be required?

From Table 25-2, the upper recommended capture velocity is 200 ft/min. For (a) the rectangular hood has an aspect ratio greater than 0.2. From Table 25-2, the applicable flow equation for this hood is $Q = 0.75V(10X^2 + A)$. The area of the opening is $[(4 \times 16)/144] = 0.444\ ft^2$. The flow required is $200[(6/12)^2 + 0.444] = 104\ ft^3/min$.

For the alternate hood (b), the aspect ratio is less than 0.2. The flow equation from Table 25-2 is $Q = 2.8LVX$. The face area is the same as the previous case. Then $Q = 2.8(32/12)(200)(6/12) = 747\ ft^3/min$.

As air moves into a hood, the area of moving air decreases and velocity increases. Changing static pressure into velocity pressure causes a loss at the entry. The coefficient of entry, C_e, represents that loss. For standard air the static pressure at the hood throat is

$$Q = 4005AC_e(SP_h)^{1/2} \tag{25-9}$$

where

SP_h is the hood static pressure in inches of water
V is in feet per minute
C_e is dimensionless
A is the area of the hood opening in square feet
Q is the air flow rate in cubic feet per minute

25-4 FLOW IN PIPES AND DUCTS

Flow Requirements in Pipes

Once captured, a contaminant moves from the hood through ducts to a point of discharge. Particulates may settle out in the ducts and build up, cause a duct to plug. The duct velocity is the air velocity in the duct and it must be high enough to prevent settling and plugging. Table 25-3 lists design velocities for ducts. Duct velocities that are too high can cause

TABLE 25-3 Design Velocities for Moving Contaminants in Ducts

Nature of Contaminant	Examples	Design Velocity (Ft/min)
Vapors, gases and smoke	All vapors, gases and smokes	Any velocity (1000–2000 is common)
Fumes	Zinc and aluminum oxide fumes	1400–2000
Very fine light dust	Cotton lint, wood flour, litho powder	2000–2500
Dry dusts and powders	Fine rubber dust, Bakelite modeling powder dust, jute lint, cotton dust, shavings (light), soap dust, leather shavings	2500–3500
Average industrial dust	Sawdust (heavy and wet), grinding dust, buffing lint (Dry), wool jute dust (shaker waste), coffee beans, Shoe dust, granite dust, silica flour, general material building, brick cutting, clay dust, foundry (general), limestone dust, packaging and weighing asbestos dust in textile industries	3500–4000
Heavy dusts	Metal turnings, foundry tumbling barrels and shakeout, Sand blast dust, wood blocks, hog waste, brass turnings, cast iron boring dust, lead dust	4000–4500
Heavy or moist dusts	Lead dust with small chips, moist cement dust, asbestos chunks from transite pipe cutting machines, buffing lint (Sticky), quick-lime dust	4500 and up

denting. Denting can damage ducts as particles impinge on duct walls and possibly create leaks.

Some materials are sticky or have electrostatic properties that cause clinging to duct surfaces. Velocity will not overcome these problems.

Designing Ducts and Pipes

To design a ventilation system, a designer must select hoods, size ducts, select bends and elbows, combine several ducts into one system, select fans and motors, move air through ducts and cleaning devices and out through exhaust stacks. The design process requires detailed analysis through each element of the system. Different operations, type of contaminant, and degrees of hazard all impact design decisions. This text does not cover the design process in detail. In general, a designer must make sure to maintain design velocities along the system. A design should have sufficient pressure at each location to achieve desired air movement in each branch and at each hood.

There are software products that assist in designing to meet the complexities of ventilation systems.

25-5 FANS

Fans, blowers, or ejectors provide air movement in local exhaust systems. Fans are most common. In most cases, fans are downstream of air cleaning devices. That prevents contaminants from affecting fan performance and service life. Blowers are usually upstream of ventilated space and often used in dilution ventilation.

An ejector provides a way to prevent contaminants from flowing through a fan. An ejector positions a fan so there is a vacuum upstream in the duct as the fan pushes air downstream without having a contaminant flow through the fan. An ejector design positions a fan so it is not in the vacuum flow that captures contaminants and blows air into the downstream flow.

Types of Fans

There are many kinds of fans. Some fans are part of a package that includes stacks or other elements of a duct system. Some fans include motors. Others require separate selection of motors. Some fans have enclosed motors tested and rated to prevent ignition of flammable dusts, gases, and vapors (see Chapters 12, 16, and 17). Table 25-4 lists types of fans and some key features of each.

Fan Selection and Fan Laws

Fan Selection Manufacturers rate fans for flow and static pressure produced. A designer must match system flow and pressure requirements to fan rating curves. The resistance of an exhaust system may vary during its operation. For example, the cleaning device may plug up and significantly increase system losses. A design must include anticipated changes in operating characteristics. Changing the speed of a motor may compensate for the additional losses and maintain the velocity and flow required.

TABLE 25-4 Types of Fans and Key Features[a]

Type of Fan	Key Features
Axial Flow	
Propeller fan	Moves large quantities of air; low static pressure; used for relatively clean air and no duct resistance; common for general ventilation
Tubeaxial (duct) fan	Fabricated in a round duct; used for condensable fumes, pigments and other materials that collect on blades; larger diameters at slow speeds are better for abrasives and accumulating material
Vane axial fan	Develops higher pressures than other axial flow fans; more economical in horsepower and space
Centrifugal	
Forward-curved blade	Squirrel cage wheel; leading edges curve toward the direction of rotation; develops low to moderate static pressure; not recommended for dusts or fumes that adhere to blades (causes imbalance and is difficult to clean)
Straight or radial blade	Paddle wheel; most commonly used fan in exhaust systems; used for materials that clog a fan wheel; medium tip speed; medium noise factor; used for heavy dust load
Backward blade	Blades are inclined in opposite direction from fan rotation; high tip speed; high fan efficiency; blade shape is conducive to buildup of material; not suited to condensable fumes or vapors
Special	
Airfoil-backward curved	Airfoils vary with manufacturer; quiet; high efficiency; blade usually has curved low vibration
In-line flow centrifugal	Backward-curved blades; special housing to fit ducts
Power exhausters, power roof ventilators	Packaged unit with fan, stack and weather protection; may be axial flow or centrifugal; various discharge patterns available
Combination fan and dust collector	Wide variety available; proper application important

[a]Derived from *Industrial Ventilation*, 28th Ed., American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 2013.

Fan Laws Flow rate, pressure produced, and horsepower vary with fan speed. However, fan speed has a different relationship with each parameter. These relationships are fan laws (refer to Equations (25-10) through (25-12)). Flow rate varies directly with fan speed, whereas total pressure and fan static pressure (FSP) vary with the square of fan speed. Air horsepower (AHP) or brake horsepower (BHP) varies with the cube of fan speed. These relationships make the selection of an efficient system and an economical one a complex process, particularly when the properties of the system vary with time.

$$FSP = SP_{out} - SP_{in} - VP_{in} \qquad (25\text{-}10)$$

where

FSP is fan static pressure (inches of water)
SP is static pressure (inches of water)
VP is vapor pressure (inches of water)

$$AHP = 5.2Q(TP)/33,000 = Q(TP)/6350 \qquad (25\text{-}11)$$

where

Q is flow rate (cubic feet per minute)
TP is total pressure (inches of water)

$$BHP = 5.2Q(TP)/33,000(E) = AHP/E \qquad (25\text{-}12)$$

where *E* is mechanical efficiency (dimensionless).

25-6 AIR CLEANING DEVICES

Very often a local exhaust ventilation system must include a capability to remove contaminants before air moves to the outdoors. Cleaning is essential for recirculated air. There are several types of air cleaning devices. Figure 25-5 illustrates properties of aerosols and related cleaning equipment.

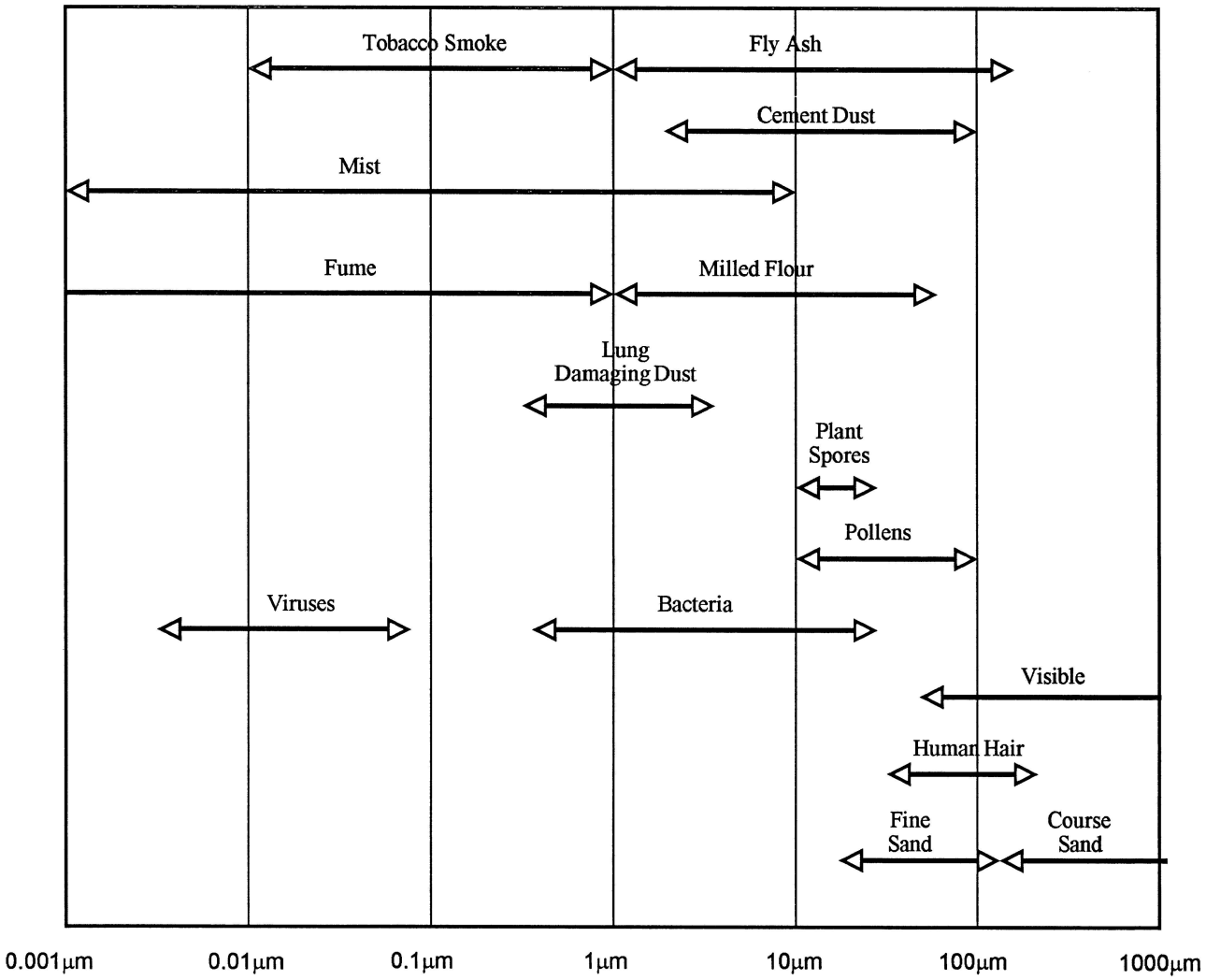


Figure 25-5. Characteristics of particles and particle dispersions.

Types of Air Cleaning Devices

The main types of air cleaning equipment are mechanical separators, filtration devices, wet collectors, electrostatic precipitators, gas adsorbers, and combustion incinerators.

Efficiency ratings for air cleaning devices removing particulates can be misleading. Consider efficiency based on mass. Collecting only a few large particles can achieve high efficiency even if nearly all small particles pass through the cleaning device. Efficiency based on particle size offers a better measure of performance. Air filters for home furnaces demonstrate this. Inexpensive fiberglass filters allow small dust particles to pass through while collecting the larger particles. Better quality filters capture the large particles, but also capture small dust particles more effectively.

Efficiency plots or curves help when selecting air cleaning devices for particulates. The curves show the portion of each size of particle actually captured.

For gases passing through an adsorption bed, such as charcoal or other material, efficiency varies with the concentration of the gas. Low concentrations have lower efficiencies per pass than do high concentrations. However, high concentrations may allow unsatisfactory concentrations to leave a bed even though they have high efficiency. Adsorption bed performance drops when an adsorbed gas reaches the adsorption capacity of the bed material.

Mechanical Separators There are several types of mechanical separators.

Gravity Chamber One type of mechanical separator is a gravity chamber. Air moves through an enclosure. Because there is a large cross-sectional area, air velocity is very slow. Gravity acts on the suspended particles as they pass through the chamber and pulls them to the bottom of the enclosure. The particles remain there until removed. A gravity chamber works for large particles. Most particles smaller than 40 μm in diameter will pass through a gravity chamber. Gravity chambers are low cost collection devices.

Impingement Separator Impingement separators are another type of mechanical separator. Dust-laden air passes through a network of baffles. Air changes direction quickly as it moves around baffles. Particulates have more momentum and cannot make the quick turns. Consequently, they impinge on the baffles and the baffles direct them to the upstream side of the flow. The clean air separated from the particulates passes out the downstream side of the baffles. Overall efficiency depends on particle size, gas velocity, and particle density. Impingement separators do not collect particles smaller than 20 μm. One advantage for impingement separators is low cost.

Cyclone Separators A cyclone collector or separator is a common mechanical collector. Contaminated gas enters tangentially into a circular chamber. The rotating gas causes particulates to move toward the outside of the rotating column. The particulates fall to the bottom and exit through a port. The partially cleaned air escapes through a vent at the top and center of the cylinder. The rotation can generate forces on the particles many times the force of gravity. Efficiency increases as the radius of a cyclone separator decreases. These separators have relatively low cost. Cyclone separators do not collect particles smaller than 5 μm. Impinging materials can erode the cylinder walls.

Filtration Devices There are several forms of filtration devices.

Mat Filters Mat filters are very porous and have low efficiency. Some filters, like those made of glass fibers, are disposable and inexpensive. Some mat filters made of other materials are washable. There is little pressure loss across these filters. As they fill, the pressure loss increases.

Ultrafiltration Filters Ultrafiltration filters, such as high efficiency particulate filters (HEPA), remove a wide range of particles. They require considerable maintenance. They also have high pressure drops across them. The pressure drop increases as the filters fill with particles.

Fabric Filters The most common filtration devices are fabric filters. There are many kinds of fabrics. Type of contaminant and temperature of the air are but two factors that affect selection. Some filters are in the form of tubes or stockings; others have an envelope or pleated form. Air moves through the fabric bags and dust collects inside them. The more material that collects, the greater the efficiency, the smaller the particles collected and the higher the pressure drop across the filter.

Many large fabric filters are self-cleaning. For some, agitation or motion shakes off the collected material and cleans the filters. Some use reverse air flow to knock material loose. During a cleaning cycle and cleaning action, exhaust system air must divert from the exhaust system to an alternate collector.

Wet Collectors The idea of wet collectors is to collect contaminants in contact with a liquid, usually water. Once trapped in the liquid, a collection system can accumulate contaminants. For some collectors the liquid and contaminants may pass through cleaning elements in the wet collector system. Examples of wet collector are spray chambers, wet centrifugals, wet filters, orifice collectors, venturi collectors, and packed towers. Some wet collectors, like packed towers, may also contain adsorption material for collecting contaminant gases and vapors. Wet collectors have advantages, such as constant pressure drop, capability to handle high temperatures and humidities, compact design, and moderate cost. Some wet collectors remove 90% of 1 μm particles. Water used in wet collectors may need treatment before disposal or reuse.

Electrostatic Precipitators Air containing solid or liquid particles passes through a bank of discharge electrodes that place a high negative charge on the particles. Collecting electrodes or plates with the opposite charge attracts the charged particles. Some precipitators have more than one stage. Electrostatic precipitators have high efficiencies, even for small particulates. They have very little pressure drop. They are expensive to operate compared to other devices.

Gas Collection There are both absorbing and adsorbing gas collectors. There are also condensing systems. If the gases and vapors have economic value, collecting or condensing them may be desirable. The efficiency of gas collection varies somewhat with the concentration of gas or vapor in the air.

Absorption Gas passing through a liquid may react with or dissolve in the liquid. This is absorption.

Adsorption Some materials, like activated carbon and alumina, adsorb certain gases and vapors at the surface of the material. The adsorbing medium may hold up to half its weight in captured gases and vapors. It is possible to reactivate the medium by heating it or flushing it with clean air to drive off the captured gases and vapors.

Cooling and Condensing Another means of removing gases and vapors from air is cooling and condensation. The system cools incoming air to form condensate. The system must then remove resulting liquid.

Combustion Incineration Combustion incinerators use oxidation to convert gases and vapors into less harmful material. However, not all gases and vapors end up in a harmless form. Combustion may involve direct flame or catalytic combustion. For some gases and vapors, efficiencies may reach 98%.

Selection of Air Cleaning Devices

There are many factors to consider when selecting air cleaning devices. Volume of air flow, concentration of contaminants, kind of contaminant and contaminant properties, temperature, pressure drop, contaminant hazards, and other factors are important. National, state, and local pollution control laws and regulations also affect the choice of collection device.

25-7 VENTILATION MEASUREMENT

There are many instruments for assessing air flow and distribution patterns for moving air.

Smoke Tubes

Smoke tubes are hand-held pumps that disperse smoke or powder visible to the eye. One can watch the movement of the smoke to see what movement patterns exist in a space or near an exhaust hood. Smoke-producing candles work the same way to aid observation of air movement.

Anemometers

Anemometers measure air velocity. Most anemometers are very directional. They must be in line with the direction of air flow for proper readings.

Impeller Anemometer Some anemometers have a small impeller moved by the air. The impeller drives a gauge that displays velocity.

Vane Anemometer Another type of anemometer has a vane that moving air deflects. An indicator connected to the vane gives air velocity.

Heat Based Anemometer Heated wire, thermocouple or thermistor anemometers measure air velocity, temperature or static pressure. Some types make nondirectional air velocity measurements.

Pitot Tube A pitot tube is a tube inserted into an airstream to measure total, velocity or static pressure. For correct readings the mouth of the tube must point into the airstream. The position of the pitot tube mouth relative to the airstream flow varies with the pressure being measured. The tube connects to a water manometer, water gage or other readout device. Figure 25-2 illustrates basic pitot tube use.

25-8 STANDARDS

There are numerous standards that set exposure limits that may rely on ventilation systems for the protection of workers, building occupants, and others. Other chapters have covered exposure standards and protection from other hazards. There are few standards that address ventilation methods, systems, and design. The Bibliography for this chapter lists references on ventilation technology and system planning and design.

OSHA Standards

OSHA has several standards concerning ventilation. For general industry,[3] standards involve ventilation for abrasive blasting, electrostatic spraying, grinding, polishing, buffing, spray finishing, spraying operations, powder coating, textiles, asbestos, and other activities. There are ventilation requirements for bulk oxygen systems, bulk plants, confined spaces, dip tanks, laundries, open surface tanks, processing buildings, sawmills, exhaust duct systems, storage rooms and open surface, and other tanks.

For construction,[4] OSHA has ventilation regulations for tunnels and shafts, compressed air, preservative coatings, temporary heating devices, and welding and cutting.

ACGIH

A long-standing publication of the American Conference of Governmental Industrial Hygienists is *Industrial Ventilation* (see note 2 in this chapter). It is a primary reference for the design of general and local exhaust ventilation systems.

Others

The American National Standards Institute, the National Fire Protection Association and other organizations have standards related to ventilation. The Mine Safety and Health Administration details requirements for ventilation of mines.[5] One can also refer to the *ASHRAE Handbook* [6] for standards and procedures for information on design of ventilation systems and related components.

EXERCISES

1. A flanged slot hood exhausts particulates produced in an operation. The flow volume for the exhaust system is 10,000 ft^3/min. The hood entry is 6 ft × 1 ft.
   - **(a)** What is the velocity at a distance 2 ft in front of the hood face?
   - **(b)** Neglecting entry losses, what is the face velocity for the hood?
   - **(c)** If the exhaust duct has a 2.5 ft diameter, what is the velocity in the duct?
2. A flexible, round, plain-opening pipe removes welding fumes. The pipe is 8 in. in diameter and is positioned so the pipe face is 8 in. from the welding operation. Assume the capture velocity produced is 200 ft/min at the point of welding.
   - **(a)** What is the flow rate in the pipe?
   - **(b)** Estimate the velocity at the face of the pipe.
3. A canopy hood hangs over an automated welding operation. The welding table and hood are both 4 ft wide and 3 ft long. The hood is 3 ft above the welding operation and the capture velocity is 200 ft/min. What flow rate is required in the hood?

REVIEW QUESTIONS

1. Name three purposes for ventilation.
2. What are the two major types of ventilation for controlling airborne contaminants?
3. Explain how clean room ventilation works.
4. Name two principles that dilution ventilation systems should meet.
5. What are the main components in a local exhaust system?
6. Define the following:
   - **(a)** static pressure
   - **(b)** velocity pressure
   - **(c)** total pressure
   - **(d)** friction loss
   - **(e)** dynamic losses
   - **(f)** make up air
   - **(g)** recirculated air
   - **(h)** capture velocity
   - **(i)** face velocity
   - **(j)** duct velocity
7. Compare the velocity of air from a jet blowing into a space and the movement of air being drawn into an exhaust entry.
8. Identify factors to consider in deciding if air should be recirculated.
9. Identify factors important in design of an air recirculation system when the air contains contaminants that are health hazards?
10. What are the fan laws?
11. Identify four types of air cleaning devices. Describe how each works. Identify an advantage or disadvantage for each.
12. What air cleaning devices handle particulates effectively?
13. What air cleaning devices collect gases and vapors?
14. Name four devices for measuring air flow.

NOTES

1 R. L. Brauer and R. L. Kuehner, "The Variability of Ventilation Codes," in *Symposium on Odors and Odorants: The Engineering View*, Chicago, January 27–30, 1969, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, 1969.

2 *Industrial Ventilation*, 28th ed., American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 2013.

3 29 CFR 1910.

4 29 CFR 1926.

5 30 CFR 75.300

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CHAPTER 26

BIOHAZARDS

26-1 INTRODUCTION

Humans have always faced dangers from biohazards. Advancements in engineering and science have reduced some of these dangers. Improvements in sanitation, sewage and sewage treatment systems, and sanitary engineering practices have reduced the dangers from many diseases in many parts of the world. Treatment of water supplies to remove biological hazards have increased the health for many societies and communities. Food inspection and handling practices have reduced dangers even farther.

However, dangers from biohazards remain. There are many current examples, such as bacteria in hot tubs and spas. There are parasitic infections from raw fish and meat and from untreated drinking water. There are dangers from molds in food, water systems, and damp parts of buildings. There are exposures to insects, plants, animals, and birds that are biohazard carriers. Humans may be biohazard carriers. There are biohazards in biological laboratories, on farms, and in food processing plants. Whether one is a consumer or worker, there are many activities that have biohazards.

There are specialty areas of practice for biological hazards. Groups that deal with dangers, exposures and toxicity of bio-hazards typically have a background in biology, especially microbiology, environmental health, or industrial hygiene. A relatively new branch of safety is biological safety. A professional organization dealing with biological safety is the American Biological Safety Association.[1] It has an alliance agreement with OSHA.[2]

26-2 AGENTS AND SOURCES

Biohazards are biological hazards from plants, animals, insects, or their products that may be infectious, toxic or allergenic. Agents are bacteria, viruses, fungi, rickettsia, or parasites.

Bacteria

Bacteria are simple, one-celled organisms. They are not visible to the eye. They multiply by simple cell division. Not all bacteria are harmful, many are useful. The shape of bacteria often characterizes them. Some are cylindrical or rod-shaped (bacilli); some are shaped like a string of beads (cocci); and some have spiral or corkscrew shapes (spirilla).

Viruses

A virus is an organism that depends on a host cell for development and reproduction. Viruses are parasitic in nature and are so small that they are not visible with an optical microscope. Viruses are transmitted in many ways. Examples are contact with infected people, contact with animals and insects, contact with contaminated equipment and contact with diseased specimens, and other means. Some viruses, such as influenza, undergo mutations. Sometimes the mutations occur quite rapidly. A mutation several steps away from an original virus may affect many people with little immunity to the mutation and create an epidemic.

Fungi

There are many species of fungi. They are parasitic in nature and grow in a living host or on dead plant or animal matter. Fungi may be microscopic in size or large. Mushrooms are examples of large fungi.

Rickettsia

Rickettsia are microorganisms that are rod-shaped and smaller than bacteria. They depend on a host for development and reproduction. They must live within a host cell. Fleas, ticks, and lice commonly transmit them. Some are airborne.

Parasites

A variety of protozoa, helminths (worms) and arthropods are parasites. They are large, multicellular organisms. They are different from other organisms that are parasitic in nature because they live in or on other plants or animals. Some well-known parasites are tapeworms, liver flukes, and hookworms.

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 26-1

July 1976, Philadelphia, PA. At the height of the nation's bicentennial celebration, members of the American Legion descended on Philadelphia for their national convention. Some 182 conventioneers staying at one of the hotels became ill and 29 died. The individuals displayed symptoms similar to pneumonia. Researchers discover a new pathogenic bacterium: *Legionella pneumophila*. This was the first pathogen identified in more than 25 years. The disease became known as Legionnaire's disease. Subsequent investigations found earlier, unidentified outbreaks of Legionnaire's disease.

The bacterium thrives in cooling tower sumps and condenser valves of air conditioning equipment. It lives in water supplies, hot water tanks of buildings and in some soils.

For the Philadelphia case, the bacterium came from the air conditioning system. The outbreak led to changes in the maintenance of air and water systems in buildings.[a,b]

[a] www.osha.gov/dts/osta/otm/otm_iii/otm_iii_7.html

[b] *Guideline 12–2000: Minimizing the Risk of Legionellosis Associated with Building Water Systems*, American Society of Heating, Refrigeration and Air Conditioning Engineers, Atlanta, GA, 2000: www.techstreet.com/products/232891

CASE 26-2

April 1985, Melrose Park, IL. *Salmonella* contamination of 1-gallon cartons of 2% milk infected more than 6,000 people in five states. At least 34 lawsuits resulted. The Hillfarm Dairy that processed the milk closed its doors. The cause may have involved the design and operation of the processing equipment. Raw, contaminated milk somehow got mixed in with pasteurized milk during the processing.[a]

[a] www.nytimes.com/1985/04/17/garden/salmonella-outbreak-is-traced.html

CASE 26-3

June 1985, Los Angeles, CA. Cheese contaminated with *Listeria monocytogenes* produced flu-like symptoms in about 150 people in the Los Angeles area. The bacterium affected mostly women and children. Some reports linked consumption of the contaminated cheese to the deaths of 62 people. The bacteria often infect cows. Pasteurization of milk prevents the bacteria from reaching consumers.[a]

[a] www.nytimes.com/1985/07/14/us/62-deaths-from-cheese-traced-to-single-source.html

CASE 26-4

Spring 1989, Northeastern US. Investigative reporters discovered a new source of potential food contamination. When trucking companies that hauled food from the Midwest to the East Coast traveled back in the other direction, some hauled garbage from eastern cities to Midwest landfills. The practice was known as "cross-hauling." There was a concern whether food might become contaminated with biohazards.

The General Accounting Office completed a study of the practice for Congress. The report found few regulations covering these activities and minimizing food contamination. The study determined that some food processors established their own standards for trailer cleanliness and which cargos a trucking company could haul beside their packaged foods. The report established that little was known about potential contamination.[a]

[a] http://archive.gao.gov/d23t8/141739.pdf

Bloodborne Pathogens

Bloodborne pathogens means microorganisms that are present in human blood and can cause disease in humans. Examples are hepatitis B virus (HBV) and the human immunodeficiency virus (HIV). OSHA established a standard addressing the safety and health of workers subject to potential bloodborne pathogen exposures.[3]

Sources of Biohazards

Zoonoses are diseases transmitted from animals to humans. They are a major source of biohazards. People who work with animals, animal products, or animal waste have a risk of infection from animal-based biohazards. In some cases, an intermediate carrier, called a vector, may move an infection from an animal to a human.

Another source of biohazards involves medical work and medical care. Examples are work in hospitals, nursing care facilities, emergency and first aid care, or work in medical, criminal, or medical research laboratories. It may include any situation in which someone can contact the blood or body fluids of animals or another human. Contact with blood can occur from treating someone injured in an accident, giving first aid treatment, participating in surgery, cleaning patient equipment, handling waste, and laundering patient linens.

Workers in hotels and other buildings can encounter biohazards during cleaning of rooms, washrooms, linens, or equipment or handling waste and waste containers.

There are potential biohazards in food processing operations. The food may be plant-, bird- or animal-based. There are biohazards in waste collection, handling and disposal, including landfills and incinerators. There are biohazards in farming and agriculture and work with animals, and in outdoor work, such as lumbering, construction, landscaping, and other activities. In the outdoor work humans may encounter insects and other creatures that may be biohazard carriers.

Table 26-1 lists examples of biohazards, occupations in which they may occur and other relevant information.

26-3 HAZARDS

The main danger from biohazards is infection. Each infection has general and/or specific symptoms. There is considerable knowledge about infections from some biohazards, however, there is limited knowledge about other biohazards. There are cures for some infections from some biohazards, but for others, there is no treatment or cure.

Some biohazard agents occur in certain geographic locations. Physicians in one country may not learn about or gain medical experience with infectious diseases from biohazard agents found in other countries. Some biohazard diseases are globally monitored, since international travel can carry a disease to new locations rapidly.

Much like chemicals, biohazard agents may enter the body through ingestion, inhalation, and skin contact. The potential for skin entry increases when there are wounds.

Classification

Federal agencies have developed a classification scheme for biohazardous agents. There are four categories or groups based on level of risk. Table 26-2 lists the four risk groups. Each higher risk group requires higher levels of protection.

Infectious Agents The U.S. Department of Health and Human Services (HHS) has developed extensive guidelines for recognizing and dealing with biohazards.[4] The guidelines identify four biosafety levels (BSL) for infectious agents and outline recommended practices when dealing with each level. Table 26-3 summarizes the biosafety levels and associated general recommendations.

Infected Animals In addition, HHS has a separate classification and standards for work with infected animals. There are four animal biosafety levels (ABSL). It follows the same biohazard safety structure as the classification scheme for infectious agents in general. However, there are additional details related to work with animals, see Table 26-4.

26-4 GENERAL CONTROLS

One can prevent many occupational infections with engineering controls, training, procedures and special equipment and facilities. The most important control is containment. HHS recommendations focus heavily on barriers between agents and workers.

Protections include engineering controls, such as biological safety cabinets, controlled access and airlocks, ventilation systems, showers, decontamination facilities, and potentially separate buildings. There are also administrative controls, such as protection from needle and other punctures and cuts (“sharps”), written manuals for operations, and other procedures. There are recommendations for personal protective equipment (PPE) for each BSL.

Laboratory Biosafety

Laboratories involved with infectious agents have significant biohazards. HHS offers recommendations for work with biohazard agents (see note 4). The recommendations help when assessing risk and preventing infections in other activities.

TABLE 26-1 Examples of Biohazards[a]

Biohazard	Sources and Comments
Bacterial	
Anthrax	Direct contact with infected animals, hides and wool. Risk is higher for veterinarians, farmers, butchers, leather and wool workers, carpet workers.
Brucellosis	Ingestion, inhalation, contact with infected animals, cuts and scratches. Those who work with cattle and hogs, meat packing workers.
Salmonellosis	Oral. Food service workers and patrons, meat and poultry workers.
Tetanus	Entrance through breaks in the skin from penetrating or crushing trauma. Persons handing jute or contact with manure.
Tuberculosis	Inhalation, contact with lesions. Silica workers, people exposed to heat and organic dusts, medical personnel, animal caretakers.
Lyme disease	Bite by infected deer tick. Contact with brush, shrubs, garden lawn, soil, mulch. Persons active outdoors such as gardeners, hikers, campers, hunters, and outdoor workers.
Fungal	
Dermatophytoses	Contact. People involved with farm and domestic animals and handlers of hides.
Histoplasmosis	Inhalation and ingestion. Roof demolition workers and workers in barns and chicken houses.
Parasitic	
Creeping eruption	Penetration of skin by infected larvae. People involved with digging in soil (ditch diggers, utility workers, laborers, masons, gardeners, plumbers).
Hookworm	Penetration of skin (particularly bare feet) by larvae. Barefoot farmers and ditch diggers, sewer workers, tunnel workers, recreation (children and adults).
Schistosomiasis	Contact with infected water. Farmers and others who stand and work in flooded areas.
Swimmer's itch	Penetration of wetted skin by snails. Workers in and around fresh water, divers, dock workers, lifeguards and recreational swimmers.
Rickettsial	
Ornithosis	Inhalation or contact with infected bird droppings. Zoo workers, taxidermists, poultry farmers and processors, pet workers and owners, people in locations where there is an accumulation of bird droppings.
Q fever	Inhalation of contaminated dusts and contact with infected animals (cattle, pigs or sheep) or contaminated substances. Farmers, veterinarians, slaughter house workers and hide and wool workers.
Rocky Mountain spotted fever	Tick bites, skin contact with tick tissue or feces. People who work outdoors, such as in lumbering, construction, forestry, ranching.
Viral	
Cat scratch disease	Break in skin, usually from animal scratch. People who work or play with cats and dogs.
Hepatitis (viral)	Fecal-oral transmission. Health workers, particularly pediatrics, oral surgeons.
Milker's nodules	Through breaks in skin. Dairy farmers and workers.
Rabies	Bite of infected animal (dogs, cats, bats, pigs, rats, etc.) People who work and play with animals or get near animals (letter carriers, delivery workers, etc.)

[a]Adapted from B. Feiner, "Occupational Biohazards," in *Dangerous Properties of Industrial Materials*, 6th ed., N. I. Sax, ed., Van Nostrand Reinhold, New York, 1984 and other sources.

The overriding principle for preventing laboratory infections is containment. The purpose is to reduce the exposure of laboratory personnel and other persons to potentially hazardous agents. Containment includes preventing the escape of potentially hazardous agents outside the laboratory to such persons as workers laundering laboratory clothing, visitors, and family members of laboratory workers. Three elements of containment include

TABLE 26-2 Classification of Biohazardous Agents by Risk Group[a]

Class	Definition
Risk Group 1 (RG1)	Agents that are not associated with disease in healthy adult humans.
Risk Group 2 (RG2)	Agents that are associated with human disease which is rarely serious and for which preventive or therapeutic interventions are *often* available.
Risk Group 3 (RG3)	Agents that are associated with serious or lethal human disease for which preventive or therapeutic interventions *may be* available (high individual risk but low community risk)
Risk Group 4 (RG4)	Agents that are likely to cause serious or lethal human disease for which preventive or therapeutic interventions *are not usually* available (high individual risk and high community risk)

[a]Adapted from 'Appendix B, Classification of Etiologic Agents on the Basis of Hazard," *NIH Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules (NIH Guidelines)*, Department of Health and Human Services, National Institutes of Health, 2013. (http://osp.od.nih.gov/sites/default/files/NIH_Guidelines.html).

TABLE 26-3 Summary of Recommended Biosafety Levels (BSL) for Infectious Agents[a]

BSL	Agents	Practices	Primary Barriers and Safety Equipment	Facilities (Secondary Barriers)
1	Not known to consistently cause diseases in health adults	Standard microbiological practices	• No primary barriers required • PPE: laboratory coats and gloves; eye, face protection, as needed	Laboratory bench and sink required
2	• Agents associated with human disease • Routes of transmission include percutaneous injury, ingestion, mucous membrane exposure	BSL-1 practice plus: • Limited access • Biohazard warning signs • "Sharps" precautions • Biosafety manual defining any needed waste decontamination or medical surveillance policies	Primary barriers; • Biological Safety Cabinets or other physical containment devices used for all manipulations of agents that cause splashes or aerosols of infectious materials • PPE: Laboratory coats, gloves, face and eye protection, as needed	BSL-1 plus: • Autoclave available
3	Indigenous or exotic agents that may cause serious or potentially lethal disease through the inhalation route of exposure	BSL-2 practice plus: • Controlled access • Decontamination of all waste • Decontamination of laboratory clothing before laundering	Primary barriers: • Biological Safety Cabinets or other physical containment devices used for all open manipulations of agents • PPE: Protective laboratory clothing, gloves, face, eye and respiratory protection, as needed	BSL-2 plus: • Physical separation from access corridors • Self-closing, double-door access • Exhausted air not recirculated • Negative airflow into laboratory • Entry through airlock or anteroom • Hand washing sink near laboratory exit
4	• Dangerous/exotic agents which post high individual risk of aerosol-transmitted laboratory infections that are frequently fatal, for which there are no vaccines or treatments • Agents with a close or identical antigenic relationship to an agent requiring BSL-4 until data are available to redesignate the level • Related agents with unknown risk of transmission	BSL-3 practices plus: • Clothing change before entering • Shower on exit • All material decontaminated on exit from facility	Primary barriers: • All procedures conducted in Class III Biological Safety Cabinets or Class I or II Biological Safety Cabinets in combination with full-body, air-supplied, positive pressure suit	BSL-3 plus: • Separate building or isolated zone • Dedicated supply and exhaust, vacuum, and decontamination systems • Other requirements outlined in the text (of the source publication)

[a]From "Section IV—Laboratory Biosafety Level Criteria," *Biosafety in Microbiological and Biomedical Laboratories*, HHS Publication (CDC) 21-1112, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Public Health Service, National Institutes of Health, 2009.

laboratory practice and techniques, safety equipment, and facility design.

Primary Containment Primary containment addresses the protection of personnel from exposure. It also seeks to prevent agents from reaching laboratory spaces. Proper practices and techniques and safety equipment aid containment. In some cases, vaccines may provide additional protection for personnel.

Secondary Containment Secondary containment refers to protection of environments outside the immediate laboratory. This requires both proper procedures and facility design.

Warnings Warnings that identify laboratories and containers with biohazards are important. The biohazard symbol (see Figure 26-1) is an essential part of a biohazard warning. Several organizations have biohazard warning requirements and standards.[5]

TABLE 26-4 Summary of Recommended (Animal) Biosafety Levels (ABSL) for Activities in Which Experimentally or Naturally Infected Vertebrate Animals are Used[a]

ABSL	Agents	Practices	Primary Barriers and Safety Equipment	Facilities (Secondary Barriers)
1	Not know to consistently cause diseases in healthy adults	Standard animal care and management practices, including appropriate medical surveillance programs	As required for normal care of each species • PPE: laboratory coats and gloves; eye, face protection, as needed	Standard animal facility: • No recirculation of exhaust air • Directional air flow recommended • Hand washing sink is available
2	• Agents associated with human disease • Hazard: percutaneous injury, ingestion, mucous membrane exposure	ABSL-1 practice plus: • Limited access • Biohazard warning signs • "Sharps" precautions • Biosafety manual • Decontamination of all infectious wastes and animal cages prior to washing	ABSL-1 equipment plus primary barriers: • Containment equipment appropriate for animal species PPE: Laboratory coats, gloves, face, eye and respiratory protection, as needed	ABSL-1 plus: • Autoclave available • Hand washing sink available • Mechanical cage washer recommended • Negative airflow into animal and procedure rooms recommended
3	Indigenous or exotic agents that may cause serious or potentially lethal disease through the inhalation route of exposure	ABSL-2 practice plus: • Controlled access • Decontamination of clothing before laundering • Cages decontaminated before bedding is removed • Disinfectant foot bath as needed	ABSL-2 equipment plus: • Containment equipment for housing animals and cage dumping activities • Class I, II or III Biological Safety Cabinets available for manipulative procedures (inoculation, necropsy) that may create infectious aerosols • PPE: Appropriate respiratory protection	ABSL-2 facility plus: • Physical separation from access corridors • Self-closing, double-door access • Sealed penetrations • Sealed windows • Autoclave available in facility • Entry through ante-room or airlock • Negative airflow into animal and procedure rooms • Hand washing sink near exit of animal or procedure room
4	• Dangerous/exotic agents which post high risk of aerosol transmitted laboratory infections that are frequently fatal, for which there are no vaccines or treatments • Agents with a close or identical antigenic relationship to an agent requiring BSL-4 until data are available to redesignate the level • Related agents with unknown risk of transmission	ABSL-3 practices plus: • Entrance through change room where personal clothing is removed and laboratory clothing is put on; shower on exiting • All wastes are decontaminated before removal from the facility	ABSL-3 equipment plus: • Maximum containment equipment (i.e., Class II Biological Safety Cabinet or partial containment equipment in combination with full body, air-supplied positive-pressure suit) used for all procedures and activities	ABSL-3 facility plus: • Separate building or isolated zone • Dedicated supply and exhaust, vacuum, and decontamination systems • Other requirements outlined in the text of the source document

[a]From "Section V—Vertebrate Animal Biosafety Level Criteria for Vivarium Research Facilities," *Biosafety in Microbiological and Biomedical Laboratories*, HHS Publication (CDC) 21-1112, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Public Health Service, National Institutes of Health, 2009.

Laboratory Practice and Technique Laboratory workers must learn which hazards exist for particular agents in a laboratory and must receive training in proper handling and operations of laboratory materials and equipment. Workers must periodically update their knowledge and skills to ensure high retention levels. There should be an operations and biosafety manual for each laboratory. The manual should identify hazards that workers may encounter and protection needed for these hazards. Persons knowledgeable in hazards, safety procedures and laboratory techniques should direct the



Figure 26-1. Biohazard symbol.

work. Knowledgeable people should complete a risk assessment and risk management plan before starting any work involving biohazards. The plan should identify dangers and implement appropriate protection.

Biosafety related to laboratory work extends into criminal laboratories. Criminal investigators and laboratory personnel handling and analyzing criminal evidence need knowledge of biohazards and protection applicable to collection, storage, handling and analysis of crime scene materials.

Safety Equipment Enclosed containers, biological safety cabinets, and personal protection equipment are the main kinds of safety equipment. The primary roles are containment and barriers. Safety containers prevent the release of unsafe substances during normal activities and operations. An example is a safety centrifuge cup.

Biological safety cabinets are partial or full enclosures where the air flow designs keep agents within the cabinets. There are three classes of cabinets:

1. Class I Biological Safety Cabinets. A Class I biological safety cabinet has an open front. Air moves inward across the face at 75 ft/min or higher and exhaust air moves through high efficiency particulate air (HEPA) filters.
2. Class II Biological Safety Cabinets. A Class II biological safety cabinet also has an open front with a 75 ft/min face velocity. It has vertical laminar flow air movement. The air moves through HEPA filters and gets recirculated within the cabinet. Some air also moves through HEPA filters before being exhausted. The filtered recirculation prevents contamination of agents by air drawn into the cabinet. National Sanitation Foundation (NSF) provides testing and certification services to ensure that Class II biological safety cabinets meet recognized standards.[6]
3. Class III Biological Safety Cabinets. Class III biological safety cabinets are complete enclosures. Workers complete activities from outside the cabinets using rubber gloves built into the cabinet walls. The gloves reach inside the cabinet and provide barriers between the agents and workers. To prevent contamination of the cabinet contents, supply air enters the cabinet through HEPA filters. The cabinet operates under at least 0.5 in. of water negative pressure. Exhaust air moves through two stages of HEPA filters. Typically, a Class III cabinet has its own exhaust fan, independent of any other ventilation systems. A cabinet may contain other equipment, such as refrigerators, dunk tanks, and centrifuges.

Beside using a Class III cabinet, one can achieve Class III standards another way. Workers wear one-piece, positive pressure, full-body protective suits containing a life-support system. They work inside Class I or Class II cabinets. In this case, the work area must have an airlock with airtight doors. Workers must pass through a chemical shower to decontaminate the suit before leaving the work area. Exhaust from the suit must pass through a two-stage HEPA filter.

Facility Design Facilities play an important role in containment. Designs protect both those working in a facility and those outside a laboratory. Designs also protect the surrounding community. There are three classes of facility design, each providing a different level of safety. The three facility classes are basic, containment, and maximum containment laboratories. Design features link to the levels of biosafety for infectious agents and for work with vertebrate animals. Tables 26-3 and 26-4 summarize the four biosafety levels. Designs include easily cleaned surfaces, special features for furniture, cleaning facilities for workers, and other features.[7]

- **Basic Laboratory** Basic laboratories support work with agents not associated with disease in healthy adults and work in which standard laboratory practices provide adequate protection. Facility designs should separate basic laboratories from public areas and office areas. There is no requirement for containment equipment.
- **Containment Laboratory** A major feature of a containment laboratory is a controlled access zone. Containment laboratories have specialized ventilation

systems and may be separate buildings or controlled access modules within a building.

- **Maximum Containment Laboratory** Maximum containment laboratories support work with agents that are extremely hazardous or may cause epidemics. Often separate buildings house these laboratories. A main design feature is highly effective barriers. They may include sealed openings, airlocks and liquid disinfectant barriers, clothing-change and shower rooms, double door autoclaves, biowaste treatment systems, separate ventilation systems, and treatment systems to decontaminate exhaust air.

Robotics Another control to reduce dangers of contact with biohazards is the use of robotics for analysis and processing of biological samples. A robot placed in an enclosure can perform many functions. The robot can reduce human handling and potential contacts by humans with biohazard agents. Automatic or manual controls operated from outside the enclosure direct the robot's actions. Some robots are designed especially for processing biohazards.

Security Security is an important consideration for work with infectious agents. There is often a need to prevent unauthorized workers and visitors from entering areas with biohazards. Potential entry may be accidental, due to curiosity or may involve threats such as terrorism. As the biosafety level increases, so does the potential need for physical security of work areas.

Security concerns include access to and use of biohazard agents by terrorists and individuals seeking to harm others. Case 26-5 discusses the appearance of anthrax in the mail. The mail pieces targeted public officials. That case caused changes in procedures for public and private organizations regarding receipt and screening of mail. The World Health Organization (WHO) has identified biological and chemical agents that pose threats. WHO lists[8] the following as significant biological agents posing threats. WHO also offers precautions for each:

- anthrax
- botulism
- haemorrhagic (hemorrhagic) fever
- smallpox
- the plague
- tularaemia

Controls include close management of inventories of high biohazard agents. There must be accounting for acquisition, storage, use, and disposal of agents and materials contaminated by them. Individuals who have any access to such agents must meet the qualifications of the organization or company holding the agents. Some organizations holding dangerous agents prohibit transport of the agents between facilities. There should be surveillance and a frequent review of inventories, practices, and individuals with access. Facilities for storing and use of such agents must have security features that may include isolation, multiple access codes, secure storage facilities, and other features.

26-5 SICK BUILDING SYNDROME AND INDOOR AIR QUALITY

Sick building syndrome is a term that emerged in the 1980s. Some describe the phenomenon as "building-related illnesses" (BRI). It stems from several incidents in which several occupants of a whole building or a certain portion of a building filed a rash of physical complaints including headaches, muscle pains, chest tightness, nausea, fever, cough, allergic asthma, allergic rhinitis, pneumonitis, and pneumonia. Often the symptoms diminished over weekends. Some individuals become sensitized or exhibited allergic

CASE 26-5

During 2001, a handful of letters containing anthrax spores were delivered to government officials or companies. Two or three people died. Postal systems and company mail departments became taxed to change procedures to protect the public and employees from potential exposures to hazardous materials transmitted by mail. Fortunately, there were few actual cases of contaminated mail. The breadth of effects was very large. The threat caused several government agencies to establish, review, and analyze procedures for dealing with anthrax and other bioterrorism threats.[a,b,c]

[a] www.fbi.gov/about-us/history/famous-cases/anthrax-amerithrax

[b] www.gao.gov/products/GAO-15-80

[c] www.cdc.gov/24-7/protectingPeople/anthrax/index.html

TABLE 26-5 Some Actions for Preventing and Controlling Sick Building Syndrome[a]

Contamination Clean Up
Remove harmful chemical sources when they exceed recognized limits
Remove dirty air filters in HVAC systems
Empty all condensate drainage trays
Use hot water to clean microbial growth from condenser coils, tubing, etc.
Swab down suspected ductwork with antimicrobial solution
Remove materials in locations found infested with microbial growth where cleaning is not possible
Clean carpeting and furniture that has microbial growth
Make sure drains in HVAC equipment are working
Preventive Maintenance
Keep hot water supply temperatures above 120 °F
Provide drains for air handling packages to prevent stagnant water
Limit relative humidity to less than 70%
Abandon air washers that use recirculating water systems
Use steam from fresh water for humidifiers, not recirculated water
Abandon spray coil systems
Keep coils, pans, drainage systems and duct work clean
Check air filters regularly and replace
Prevent stagnant water
Preventive Design
Locate intake vents where they receive fresh air and not contaminated air
Use only steam humidifiers, not recirculating ones
Use prefilters to clean air upstream of high efficiency filters
Design HVAC systems to handle varying resistance to air flow in buildings
Locate HVAC system components where it is easy to inspect and service them

[a]Adapted from V. L. Bishop, D. E. Custer and R. H. Vogel, "The Sick Building Syndrome: What It Is and How to Prevent It," *National Safety and Health News*, vol. 132, no. 6: 31–38 (1985).

reactions to work conditions. A recent term is multiple chemical sensitivities (MCS). In many cases, it was not possible to identify a precise link between symptoms and conditions in the building. Case 25-2 provides an example.

ASHRAE defined the term "sick building" as a building in which a significant number (more than 20%) of building occupants reported illnesses perceived as building-related.[9] Researchers began looking into these problems. They identified several possible causes. One cause included contaminants entering air conditioning units from birds. Investigations found the development of microbial slimes in air handling units. Researchers found that condensate pans, humidifiers, and tanks of coolant from machining can form places for organisms to grow. Hot water supplies that are not hot enough can incubate bacteria. Beside biological contaminants, there are often chemical contaminants from smoking, off-gassing of new furniture and carpet, asbestos particles from insulation and other applications. In some cases, polychlorinated biphenols (PCBs) are released from exploding or burning electrical transformers. Poor lighting and acoustics also contributed to sick building syndrome. Another possible cause was tight building construction, where there is little infiltration of outdoor air. Other contributing factors are release of formaldehyde from certain foam insulations and flooring and release of other contaminants from heating, cooking, and power machinery. Emissions from powered industrial vehicles can contribute. Researchers continue to identify the complexities of this problem and its corrections.

Controls vary with the problem. Chlorination and other chemical treatments commonly used for water-based problems in HVAC equipment may not be effective. Designated smoking areas have not always removed contaminants from the general office environment. When contaminants build up as a result of an inadequate supply of outdoor air, likely sources of contaminants for sick building syndrome are the HVAC systems. When located, the specific causes require removal at the source.

ASHRAE incorporates recommendations for the prevention of occupant complaints into its standards for ventilation in buildings.[10] EPA offers some publications on indoor air quality and radon. Table 26-5 lists some actions for preventing and controlling sick building syndrome.

26-6 GENETIC ENGINEERING

In the 1950s, researchers discovered the double helix of deoxyribonucleic acid (DNA), the building block of life. Since then research has mapped the complete DNA molecule for humans and many animals and plants. DNA testing is now common. Genetic engineering, cloning, and gene splicing have increased rapidly and created commercial products, particularly in agriculture and food products. In 1980, the U.S. Supreme Court decided that a live, laboratory-made microorganism is patentable. This decision let stand a lower court decision for the first patent on genetically engineered materials. The patent recognized a General Electric product—an oil-eating organism. Genetic engineering has produced biological growth of insulin, interferon, and bacteria capable of digesting 2,4,5-T, the key chemical component in Agent Orange. Other useful products have also emerged from biotechnology research.

Genetic engineering, gene splicing, and cloning led to public fears about modifying DNA. Modified organisms, plant and animal species produced in error or for destructive purposes made some people fearful. Their fear arose from incidents similar to the black plague of the Middle Ages and the worldwide influenza epidemic of 1918 that killed 20 million people. The National Institutes of Heath (NIH) developed guidelines for recombinant DNA research.[11]

A major control to prevent dangerous releases of new organisms is careful review by government and private

agencies. Regulations and guidance struggle to keep pace with the rate of technology applications.

There are few methods for evaluating the safety of genetically engineered products. Risk analysis techniques are useful. Major differences in standards and procedures exist among countries regarding acceptance of genetically modified organisms (GMO) that enter food supplies.

26-7 OTHER BIOHAZARDS AND CONTROLS

There are many other ways biohazards can threaten people in daily living, during work, and in special environments. Biohazards in the food chain threaten many people. Biohazards in hospitals require careful control to prevent transfer of infections and disease.

Food

Biohazards enter the food chain at many points. For example, a natural bacterial growth in corn stored in grain bins and elevators can produce a toxic substance called aflatoxin. Farmers, grain elevators, and grain companies must monitor corn for this toxin. In some seasons it is a greater problem than others. The U.S. Department of Agriculture has numerous standards for and conducts inspections on grain and other food materials. These standards and other controls ensure that plant and animal foods pose little risk of biohazards for consumers.[12] The Department of Commerce has standards for fish and seafood products.[13] The Food and Drug Administration sets standards on food for human consumption[14] and food for animals that are kept for human consumption.[15]

Restaurants and Food Establishments

State and local governments have public health inspectors who regularly inspect restaurants and related food establishments. Regulations require workers to handle properly, refrigerate, and process food for customers. Regulations also prevent the spread of biological agents by insects, such as flies, and by rodents through sanitary practices. Establishments that do not meet inspection standards must resolve deficiencies or face temporary or permanent closure. A major problem in food preparation and service at restaurants and hotels is getting employees to wash their hands and adhere to other basic personal sanitation practices.

Hospitals and Other Health Care Facilities

Federal regulations for the construction of medical facilities[16] include features that help minimize hazards of biological agents. State regulations and certification programs for medical facilities also help establish controls to minimize the dangers of biological agents. The American Hospital Association (AHA) and other health care organizations have their own guidelines that assist the operators of facilities to minimize biohazards and any resulting infections. There are also inspections and accreditations for health care facilities. Refer also to Chapter 30.

Swimming Pools, Spas, Saunas, Therapy Pools, and Tanning Booths

A variety of public facilities create opportunities for the transfer of biohazards. Proper design, operation, cleaning and maintenance are important in controlling biohazards. Each recreational facility may have other safety and health hazards requiring additional controls.

Water in swimming pools becomes contaminated by microorganisms from swimmers' skin, mucus, feces and urine and from dirt, plant material, and other sources. Water supply and recirculation systems must keep water clean and disinfected. Recirculation systems pump water through filters to remove hair, lint, and other large particulates. Operators backwash filters to flush collected materials into waste containers or sewer lines. Chlorine and other chemicals disinfect the water. The rate of filtration and disinfecting depends on the number of swimmers and tests of water samples. There are state and local codes for the operation of public swimming pools. There are many sources of criteria for design of large pools.

Spas, therapy pools, hot tubs, and similar water containers that have multiple users require treatments similar to swimming pools. The heated water increases the rate of growth for biohazard agents. Simply draining the containers, flushing out solids and scrubbing them regularly with disinfecting detergents will help prevent the transfer of biohazards.

Other recreational facilities that many people use require care in preventing the transfer of biohazards. Cleaning, disinfecting, and other means will help prevent infections.

Plumbing, Sanitary Sewer Systems, and Water Supplies

The implementation of sanitary sewer systems and treated water supplies has protected the public from many kinds of biohazards. State and local governments have plumbing codes, codes for sanitary sewer systems, and codes for water supply systems. In many locations, plumbing and sanitary lines require inspection when initially installed or modified. Strict code enforcement prevents potential disease transfer. Careful separation of potable water from untreated water supplies and sewer lines prevents cross-contamination or back flow to the potable water.

Ventilation and dehumidification in closed spaces can help prevent the growth of molds. Treatment of standing water in air conditioning equipment can also minimize the opportunity for molds to grow.

Outdoor Work

Many people work in outdoor settings. Exposures to animals, other creatures, insects, and dangerous plants offer the potential to catch diseases from biohazard agents. Outdoor workers need training and reminders about potential exposures. They need preventive items that include repellants for insects and spiders. They need proper clothing to prevent bites to feet, ankles and legs. When work begins at a new work site, an employer should complete a risk assessment that includes identification of biohazards and the creatures that may carry them. It should include a risk management plan that identifies the training required, the special equipment, supplies, and clothing. It should include preparation for emergency procedures, evacuation, and treatment.

EXERCISES

1. Visit a water treatment facility, biological laboratory or other facility to find out what biohazards it encounters. Identify how the facility controls biohazards during operations.
2. Find out how a hospital manages and controls biohazards.
3. Research the events surrounding a major biohazard incident.
4. Research the scope of biohazard problems in the world, particularly developing countries that have poor water supplies, limited sanitary sewers, and treatment plants. Identify practices that lead to biohazard infections and illnesses. Identify ways to minimize these hazards.
5. Visit a food processing plant and find out what measures are in place to control biohazards.
6. Investigate state and local regulations governing food handling and service in restaurants and eating establishments. Determine how public health and sanitary inspection agencies complete and score establishments. Obtain the records of inspection scores for a group of local restaurants for the last six to twelve months.
7. Investigate various types of molds and identify the hazards each presents. Review methods for removal or treatment and the safety and effectiveness of each method.
8. Find out how a hotel monitors for the presence of bedbugs and what actions they take once they find bedbugs in their facility.
9. Contact a local employer that provides landscape services or has workers in wooded areas. Find out how the company protects its workers from insect dangers.

REVIEW QUESTIONS

1. What are the five kinds of biohazard agents?
2. What are zoonoses?
3. What is the main danger from biohazards?
4. What are the four classes of biohazards in order of hazard severity?
5. What is the main goal of controls for biohazards in laboratory work?
6. Characterize Class I, Class II and Class III biological safety cabinets.
7. Define sick building syndrome. What is an alternate term for it? What symptoms do people typically exhibit with sick building syndrome? What agents are commonly involved?
8. What are potential hazards for genetic engineering? What controls are there?

NOTES

1 www.absa.org

2 www.osha.gov/dcsp/alliances/absa/absa.html

3 29 CFR 1910.1030, Bloodborne Pathogens. www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=10051&p_table=STANDARDS

4 *Biosafety in Microbiological and Biomedical Laboratories*, 5th ed., HHS Publication (CDC) 21–112, Public Health Service, Centers for Disease Control, U.S. Department of Health and Human Services, March 2009. www.cdc.gov/biosafety/publications/bmbl5/

5 Examples are: 29 CFR 1910.145 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9794, and 49 CFR 172.323 www.ecfr.gov/cgi-bin/text-idx?SID=94c5c006f38890b0fb041336e4b45e94&node=se49.2.172_1323&rgn=div8

6 *Biosafety Cabinetry: Design, Construction, Performance, and Field Certification*, NSF/ANSI 49–2012, National Sanitation Foundation International, Ann Arbor, MI, 2012.

7 See details for each class of facility in *Biosafety in Microbiological and Biomedical Laboratories*, 5th E ed., HHS Publication (CDC) 21–112, Public Health Service, Centers for Disease Control, U.S. Department of Health and Human Services, March 2009.

8 *Public Information on Biological & Chemical Threats*, World Health Organization, 2003. www.who.int/csr/delibepidemics/biochem_threats.pdf

9 *Indoor Air Quality—Position Paper*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, approved by the ASHRAE Board of Directors, August 11, 1987.

10 ASHRAE/ANSI 62.1-2013, Ventilation for Acceptable Indoor Air Quality, ASHRAE, Atlanta, GA, 2013. ASHRAE/ANSI 62.2-2013, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*, ASHRAE, Atlanta, GA, 2013.

11 *NIH Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules*, National Institutes of Health, U.S. Department of Health, Education and Welfare, November 2013. http://osp.od.nih.gov/sites/default/files/NIH_Guidelines_0.pdf

12 7 CFR and 9 CFR contain regulations on food safety.

13 50 CFR 260.

14 21 CFR 100.

15 21 CFR 500.

16 42 CFR 124.

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CHAPTER 27

HAZARDOUS WASTE

27-1 INTRODUCTION

For many years, there was little concern about waste. For waste from home, people burned it, buried it, fed it to animals and birds, or left it for a garbage hauler and forgot it. For industrial production, engineers and managers often divided items into product and by-product. In some cases, a producer could find a buyer for some of its by-products. In many cases, by-products were simply waste. In those times, there was little regulation about what people got rid of, how they handled it or where they sent it. Some municipalities had waste collection services and burned combustible materials in incinerators. In other cases, they buried or dumped waste.

Adding to the problem was the growth in the amount and types of waste. Today, consumers purchase food and other items in all kinds of special packaging not used in the distant past. The variety of product materials grew. Some waste did not burn, rust, or decay naturally. At one time there were few plastics. Today, plastic waste is common.

In agriculture for example, at one time there was little use of chemicals. That slowly grew with the addition of chemical fertilizers to replace or supplement animal waste as fertilizer. Later, use of herbicides and insecticides became common. The variety and volume of waste continue to expand.

Some examples illustrate the waste and hazardous waste problems.

Love Canal, New York

After Love Canal, near Niagara Falls, NY, received national attention (see Case 27-1), a study by New York State[1] reported that companies had dumped nearly 22,000 tons of chemical waste into Love Canal (see Table 27-1). The study also found that 152 of 215 waste disposal sites in Niagara (Niagara Falls area) and Erie (Buffalo area) Counties of New York had had or potentially contained hazardous waste. Some contained even more waste than Love Canal. One site contained entire tank cars of waste.

Investigators found that the "Valley of the Drums" near Shephardsville, Kentucky, contained between 17,000 and 100,000 illegally abandoned drums. No one knew the contents of most drums. (See Case 24-3.)

Cumulatively, the many stories about hazardous waste alerted the public to the problem. New laws continue to emerge. Some locations even have banned disposable baby diapers, a product for the modern family, unless the diapers have biodegradable materials. However, biodegradable plastics do not degrade easily in landfills when isolated from air. Engineers face a growing challenge to create products from materials that create fewer waste problems. In addition, there is a need to find more effective methods for managing waste, particularly hazardous waste. The public in the "throwaway" society faces a challenge to reduce the volume of waste through recycling, changed packaging, and other means.

27-2 HAZARDOUS WASTE

This chapter addresses some aspects of hazardous waste. The focus is on waste that creates hazards for safety and health of workers and the public. This book leaves discussion of other aspects of waste to other sources. This discussion focuses on U.S. issues. The U.S. was first to recognize and deal with the hazardous waste problems through legislation and regulation.

The Hazardous Waste Problem

Hazardous wastes comprise a small portion of the total waste generated in the United States. The U.S. EPA estimated the United States produces more than 80 billion pounds of hazardous waste each year. Others believe the amount is higher.[2] The EPA estimated that for a time only 10% of these wastes had proper disposal through on-site disposal methods and secured landfills. The remainder go to unlined lagoons and ponds, non-secure landfills or disposal in other ways. Alternate disposal methods include recycling, ocean dumping, placing waste in sewer systems, dumping on roads, deep-well injection or burning in ordinary incinerators. An EPA survey in 1980 produced a list of more than 32,000 known

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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TABLE 27-1 Waste Content of Love Canal

Type of Waste	Estimated Quantity (tons)
Miscellaneous acid chlorides	400
Thionyl chloride	500
Miscellaneous chlorinations	1,000
Mercaptans	2,400
Trichlorophenol	200
Benzoyl chloride	800
Metal chlorides	400
Liquid disulfides	700
Benzyl hexachloride	6,900
Chlorobezenes	2,000
Benzyl chlorides	2,400
Sulfides	2,100
Miscellaneous	2,000
Total	21,800

waste sites containing hazardous waste. These results led to tighter disposal regulations, a Superfund cleanup program for existing hazardous waste sites, and increased liability for owners of contaminated land. More recent legislation has reduced the disposal options and tightened standards to improve and control hazardous waste management.

There are two categories of wastes. Producer wastes are those generated by industry. Most producers confine them to particular locations. Consumer wastes are those disposed of by the ultimate user of products. They are usually low in concentration, but widely dispersed.

On June 13, 1989, the EPA released a list of 595 waterways (rivers, creeks, streams, oceans, and lakes) across the United States that have pollution levels higher than acceptable levels for 126 chemicals considered harmful to the environment. More than 17,000 other waterways have contaminants at lower levels or contain other substances. Based on these studies, the EPA developed cleanup plans. With the implementation of those plans, the hazardous waste problems have diminished or are coming under control.

Hazards

The major hazards of waste are those already identified in Chapter 24 for various substances. The characteristics include

- ignitability (flammability under fire protection terminology)

CASE 27-1

August 2, 1978, Love Canal, NY. On August 2, 1978, state officials ordered the emergency evacuation of 240 families from the Love Canal neighborhood of Niagara Falls, New York. Residents who had experienced family illnesses and became aware of the dangers found in the soil of their yards had heated confrontations with government officials. Some events made national news. Eventually, officials took action to help residents relocate. With Love Canal and the TV coverage, the eyes of the nation opened to the problems of hazardous waste in the United States.

Love Canal began in 1880 as the dream of William T. Love. He began construction on a dream city surrounding an electrical generating plant. The idea was to use diverted water from the Niagara River to produce direct current power. A canal from the river would provide water to the plant. However, project costs and the invention of alternating current ended the dream during its early development. Alternating current could travel long distances. Direct current could not. Between 1942 and 1952, the abandoned canal became a dumping ground for waste from local chemical plants. In 1953, Hooker Chemical Company, the owner of the site, deeded the land to the local school district for $1.00. The district built a school playground on the site and developers constructed housing on and adjacent to the site. The new owners had no knowledge about the contents of the site.[a]

[a]Michael H. Brown, *Laying Waste: The Poisoning of America by Toxic Chemicals*, Pantheon Books, New York, 1979.

CASE 27-2

1971 and 1982, Times Beach, MO. The Centers for Disease Control began investigating Times Beach, Missouri, in 1971. On December 23, 1982, CDC issued a warning to residents of Times Beach that their town was unsafe because of dioxin (2,3,7,8-tetrachlorodibenzoparadioxin or TCDD) contamination. Sax lists TCDD as a "very, very toxic material." Just two weeks before, the town's residents had faced a record flood of the Merimac River. After the 1982 warning and evacuation of residents, the federal government removed contaminated soil from the community at a multimillion dollar cost.[a]

[a]www.legendsofamerica.com/mo-timesbeach.html

CASE 27-3

April 22, 1980, Elizabeth, NJ. A major fire on the waterfront of Elizabeth, New Jersey, consumed thousands of containers of hazardous materials and gave off noxious smoke and gases. The site collected and stored the waste containers. No one knew their exact contents. It took years to complete cleanup of the site.[a]

[a]www.state.nj.us/health/eohs/union/elizabeth/chemical_control/chemcon_sru_9_92.pdf

CASE 27-4

1940s and 1990s. Grand Junction, Colorado. Radioactive mine tailings form the foundations of houses and yards in some uranium mining communities in Colorado and Wyoming. Uranium mining and processing began in the early 1940s for the WWII Manhattan Project. The radioactive tailings acted like sand and found uses in concrete, mortar, stucco, yard soil, and similar applications. That left a major cleanup task for Grand Junction, Colorado, and other communities.

In 1990, the Department of Energy estimated that the immediate costs to clean up contaminated nuclear production facilities and their sites would be $30 billion.[a,b]

[a]www.colorado.gov/pacific/sites/default/files/HM_umilltail-Uranium-Mill-Tailings-Management-Plan_1.pdf
[b]www.wmsym.org/archives/1998/html/sess29/29-07/29-07.htm

CASE 27-5

July 1988, New Jersey shores. In the summer of 1988, medical waste washed ashore at several public beaches along the east coast of the United States. Waste transporters improperly had dumped the materials at sea. It created a panic that summer for those using the Atlantic Ocean beaches.[a]

[a]www.nytimes.com/1991/09/11/nyregion/beach-medical-waste-debris-but-no-panic.html

- reactivity
- corrosivity
- toxicity.

In addition, damage to the environment is important. Hazardous materials may contaminate groundwater and water supplies, cause the closure of wells, destroy natural habitats, contaminate soil, kill fish or livestock, incapacitate sanitary sewer treatment facilities, damage crops, or contribute to air pollution. Hazardous waste may also have biohazards, covered under toxicity.

Hazardous Waste Definition

As a result of the Resource Conservation and Recovery Act (RCRA) of 1976, the Environmental Protection Agency created a complicated definition for a hazardous waste. Hazardous waste is a waste with properties that make it dangerous or potentially harmful to human health or the environment. They may take many forms, such as solid, semi-solid, liquid, or gases.

Sources of Waste There are two sources of hazardous wastes. One group consists of the more than 20,000 hazardous waste generators, mainly larger companies. Households make up the other group. They are homes that purchase products and end up with hazardous materials, such as unused paint, batteries, oil, and other items. RCRA does not regulate home-generated hazardous wastes.

Identifying Hazardous Wastes The EPA established two categories to identify whether wastes are hazardous. The two categories are characteristic wastes and listed wastes.

Characteristic Wastes Characteristic wastes exhibit one or more of the four hazard characteristics:

- *Ignitable wastes* can create fires under certain conditions, are spontaneously combustible, or have a flash

point less than 140 °F. Examples are waste oils and solvents.

- *Corrosive wastes* are acids ($pH \leq 2$) or bases ($pH \geq 12.5$) capable of corroding metal containers, such as storage tanks, drums, and barrels. An example is battery acid.
- *Reactive wastes* are unstable under normal conditions. They can cause explosions, toxic fumes, gases, or vapors when heated, compressed, or mixed with water. Examples are lithium sulfur batteries and explosives.
- *Toxic wastes* are harmful or fatal when ingested, inhaled or absorbed through the skin. Toxic wastes in landfills may leach from the waste and pollute ground water. Examples are materials containing mercury and lead.

Listed Wastes Listed wastes appear on one of four EPA hazardous waste lists:[3]

- *The F-list* (wastes from non-specific sources) identifies wastes from common manufacturing and industrial processes. Examples are solvents for cleaning or degreasing operations.
- *The K-list* (wastes from specific sources) includes certain wastes from specific industries. They may be certain sludges and wastewaters from treatment and production processes from specific industries. Examples are petroleum refining or pesticide manufacturing.
- *The P-list* (discarded commercial chemical products) includes specific commercial chemical products in an unused form. Examples are pesticides and certain pharmaceutical products that become hazardous when discarded. The P-list includes acutely hazardous chemicals.
- *The U-list* (discarded commercial chemical products) is very similar to the P-list. The U-list contains chemicals containing toxic constituents.

Listed Wastes Codes Each listed hazardous waste has one or more codes and Table 27-2 lists the hazard codes. Many hazardous wastes meet the definition of more than one waste type. If a hazardous waste becomes mixed with a solid waste, usually the resulting mixture is a hazardous waste. This prevents dilution as a way to seek exception from regulation.

EPA has subcategories within hazard codes. It uses certain tests and standards to identify the code and subcategory for a chemical.

RCRA Definition

Under RCRA, all hazardous wastes are solid wastes. A solid waste is one form of waste.

TABLE 27-2 EPA Hazard Codes by Waste Type

Waste Type	Hazard Code
Ignitable	I
Corrosive	C
Reactive	R
Toxicity characteristic	E
Toxic	T
Acutely hazardous	H

To determine whether a waste is an EPA hazardous waste, one must make two determinations. The first task is to determine if a waste is a solid waste. The second task is to determine whether a solid waste is a hazardous waste.

EPA also considers whether recycled substances are hazardous waste and how to apply hazardous waste rules to them.

Solid Waste RCRA does not use the physical form of a material to determine whether it is a solid (in contrast to liquid or gas). RCRA defines a solid waste as:

> Any garbage, refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility, and other discarded material, including solid, liquid, semisolid, or contained gaseous material, resulting from industrial, commercial, mining, and agricultural operations and from community activities.

In short, a hazardous waste is any material that meets the RCRA definition of a solid waste and is not excluded as a hazardous waste.

It becomes somewhat complicated to determine whether a waste is a solid waste and also a hazardous waste. Figure 27-1 provides a logic chart for making those two decisions.

Referring to Figure 27-1, materials are one of three categories:

1. Garbage, refuse, or sludge.
2. Solid, liquid, semi-solid or contained gaseous material.
3. Other.

These categories help determine if materials are RCRA solid wastes.

A material that is a RCRA solid waste requires further evaluation to see if it is a RCRA hazardous waste. The two categories discussed above, characteristic wastes and listed wastes, establish whether a solid waste is a hazardous waste.

RCRA excludes some substances. Examples are domestic sewage, irrigation return flow, point source discharge, certain mining waste, special nuclear, and other materials. Other laws cover them and other regulations control them.

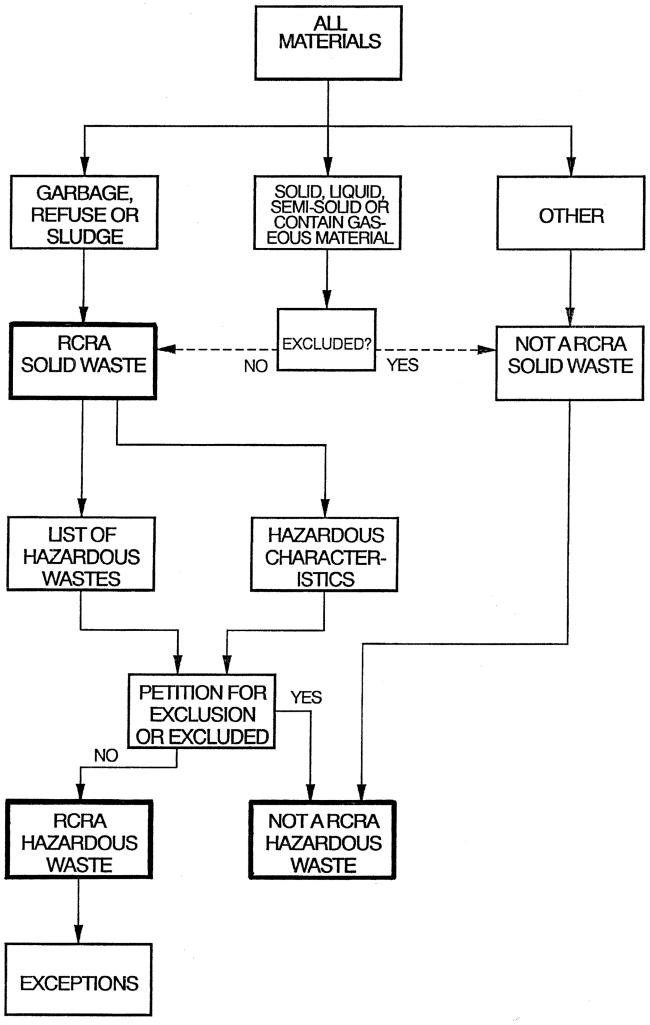


Figure 27-1. Logic tree for EPA definition of a hazardous waste.

EPA uses evaluation standards and methods to determine if potential substances are included or excluded as hazardous waste. EPA regulations provide details on possible exclusions.

Waste generators must document the hazardous waste determination process and keep records of test results, waste analysis, and other aspects of their decisions.

Beside the EPA definitions, there are other ways to classify hazardous waste. For example, how long a material remains hazardous is important. Some materials, like heavy metals, remain toxic for extended periods. Most often a hazard is an intrinsic property of a material. Some materials lose their hazardous property over time at a moderate rate. Other materials, such as acids or bases, may lose their hazardous property rather quickly in contact with other materials.

Hazardous Waste Problems

A number of practices add to the general waste problem. The hazardous materials portion of the waste has gained public attention and brought about new laws and regulations accompanied by new technologies. There were significant efforts to clean up hazardous waste sites. However, many waste sites resulting from poor practices of the past will be with us for some time.

A serious problem in the past was hazardous waste management. Not that long ago people got rid of hazardous waste by passing it along. One simply called a waste hauler and paid to have it removed. There was little concern on the part of waste generators, whether consumer or producer, about what happened to waste after someone hauled it away. Engineers and others received little training about what to do with materials no longer needed or left over from manufacturing processes. Laws and regulations changed this approach. Improper disposal has not disappeared totally.

Another problem stems from our "throwaway" society. We design some products for disposal after we are through using them or after they fail. Many electronic products become obsolete because of technology changes, so we throw them away. There is no way to upgrade personal computers, laptops and phones. Few are worth repairing if they fail. They become waste. Much of the waste generated is reusable or recyclable, but people don't know who collects them. In many cases reuse and recycling are not economical, so no one collects the items. The volume of throwaway products and packaging adds to the waste problem.

Another problem of the past was selection of waste sites. We located dumps on the least desirable land, land of little value for agriculture, business or residences. Unfortunately, the undesirable lands were often wetlands or land with porous, sandy soil. They allowed materials dumped in these sites to migrate into surface and underground water supplies. Recovery of these leaching materials is extremely difficult.

Beside selection, waste site design created additional problems. There was little design for dumps and landfills. Someone dumped waste or piled it up. See Case 16-3. Sometimes waste got covered. Little attention was given to preventing dump contents from leaching into the soil below or to nearby areas.

Another problem is liability for past dumping. It was not uncommon in the past that companies transferred waste to waste management and disposal companies. Later, the waste company went out of business. Under current law, the parties involved including the generator, have a financial liability for the cleanup of sites contaminated by their waste. The liability and cleanup costs for past practices, even if well managed under previous standards, can be very high. Selling a plant to another company does not always relieve the first owner of financial responsibility if there was contamination

of the site. The new owner may pay little for the site or facility. However, failing to investigate the property for hazardous waste may drive the real price high after including cleanup costs.

Today, laws, regulations, and standards impact both old and new waste and waste sites.

27-3 CONTROLS FOR HAZARDOUS MATERIALS

There are many choices involved in reducing the dangers from hazardous waste. The appropriate and best choice will vary with particular materials.

There are many methods for dealing with waste. Methods include eliminating the hazardous material, reducing quantities generated, restricting the area contaminated by containing the waste, storing the waste, and separating wastes by degree of hazard. There are also pretreatment, treatment, detoxification and disposal. Other methods include reusing, recycling or reclaiming materials and managing distribution.

There are many factors that affect the choices available. One factor is laws and regulations. Federal and state laws and regulations specify acceptable methods for different hazardous materials. Some methods are not technically feasible or practical for particular materials.

Social and political factors play an important role. For example social responsibility and sustainability (see Chapter 1) are important considerations today. They impact a company's image and the public's perception of a company.

Potential litigation is also a factor. Some communities do not want landfills, incinerators, recycling or other hazardous materials processes located in their area. "Not in my backyard" is a common public theme. There are many court cases in which individuals and communities challenged locations for existing and proposed waste control facilities. Even at the national level the process of selecting disposal sites for hazardous waste and radioactive waste can drag on and on.

Cost is another critical factor. It is necessary to keep the waste management and treatment costs as low as possible. The cost of disposing of hazardous waste has increased dramatically. Some companies pay several hundred dollars or more per 55-gal. drum for hazardous waste removal and disposal. In many cases, the costs impact the consumer. For example, auto supply stores often add a disposal fee to the final price of each tire and battery sold. Oil changes for cars often include a waste disposal or recycling fee. There are few new companies entering the hazardous waste business and there are fewer and fewer approved waste sites. Haul distances are long for many parts of the country, particularly the east and northeast. Hazardous waste companies or would-be companies have difficulty obtaining liability insurance. The insurance is expensive and usually does not exceed one million dollars. Because the generator of waste has a responsibility for the waste, it is expensive to managing waste processes and waste records. The generator has expenses even when they transfer wastes to someone else.

Eliminate Hazardous Wastes

A good way to minimize the dangers of hazardous waste is to prevent their generation. This may be possible by substituting less hazardous material in a process or using materials that do not produce hazardous waste. One may also change a process. This may prevent the generation of hazardous waste or reduce the amount of hazardous material used or created.

Reduce Hazards of Waste

Another approach is to reduce the hazards of hazardous waste. This may involve separating hazardous waste from other solid waste. That reduces the volume of waste classified as hazardous waste. It may involve using different materials that are less hazardous. It may involve reusing hazardous waste. In a few cases, composting may be an option to reduce pathogens and other hazards.

Reduce Quantities

Sometimes it is impossible to eliminate hazardous waste completely. However, the high costs associated with hazardous waste management and disposal provide incentives to produce as little as possible. There are several possible approaches. Some reduction strategies prevent hazardous waste generation. Some apply to the waste produced.

Analysis and Plans An important approach is analysis of waste streams and formulation of a hazardous waste reduction plan. Some have suggested three phases in a waste minimization program. Each phase must deal with hazards, risk, and economics of options. It is important to involve both managers and workers in each phase. Follow-up for each phase must evaluate the effectiveness of actions taken or to be taken:

First Phase The first phase is reviewing and improving operating practices. It is important to document the existing processes that create hazardous wastes. Documentation activities should compile management policies and procedures, employee training, maintenance practices, purchase of hazardous materials, risk analysis, and process decision-making.

Second Phase The second phase addresses processes in greater depth through a feasibility study. The options for reducing hazardous waste may involve changes in processes and equipment, quality control, and instrumentation. Studies of options must evaluate cost, process

reliability, on-site and off-site safety, potential waste reduction, regulatory compliance, and other factors. Another possible action is applying simulation methods to determine the reliability and economics of potential process changes.

A variety of actions may apply. For example, management changes and employee training may be part of the plan. Other possible actions are hazardous material inventory control from procurement through disposal and keeping different waste streams separate. A process change may be as simple as buying the minimum quantity needed instead of large quantities that have low purchase costs and high disposal costs. Improved materials handling practices and preventive maintenance programs may reduce the chances of spills and leaks.

Final Phase The final phase is the selection and implementation phase. Based on studies of possible process changes, an organization decides which changes to fund and implement. The selected changes require final design and then process modifications. Implementation may require participation by process equipment vendors and contracted services. This phase requires evaluating vendors carefully to ascertain what experience they have in waste minimization and how well their products will work when installed. Other individuals will have to prepare changes in policies and procedures, training programs, and monitoring and record-keeping details.

Reuse, Recycle, Reclaim

One way to minimize hazardous waste is to reuse, recycle, or reclaim materials. For example, there are many processes that require solvents. In some cases the solvent may evaporate. Because regulations prohibit exhausting it to the atmosphere, recovery is necessary. Recovery may involve condensation, adsorption or other means. It must convert to a reusable form.

Some processes may contaminate a solvent. Then, a user may reprocess it or use a reprocessing service to make it re-useable. Another approach may modify the solvent and its properties so the waste has economic value to someone else. The generator may sell it for use by another company. There are a number of waste exchanges among industrial groups and companies that help waste producers find potential users.

Containment

Containment is another important option for controlling the generation of hazardous waste. Processes and operations should have designs to minimize the amount of air, water, and other materials that become contaminated by hazardous material. The less material contaminated, the less there is to manage. For example, if one allows waste materials to mix with storm water, the task of removing contaminants increases substantially. A large volume of water requires treatment to remove the contaminants.

Special equipment and devices may help contain contaminants. For example, sensors placed in sewer lines may detect the presence of hazardous waste. If hazardous waste is present, the lines can divert flow to holding tanks and prevent spills into sewer systems and waterways. That allows time to correct the hazardous materials flow problem or to process the content of holding tanks to remove hazardous waste.

Storage

There is not always a place to put hazardous waste. After generating hazardous waste, there is a need to hold it for subsequent transport and processing. That could occur in batches. Removal from the site may require waiting until there is a full truck load or a reasonable quantity for transport.

Liquid storage may involve tanks (underground or above ground) or open lagoons. Solid waste may be waste piles or other forms of surface impoundment. Wastes located in one place should be compatible. For example, it is not good to mix strong acids with strong bases. In many cases, different wastes or types of wastes require separate containers when they are incompatible. It is important to check container condition to prevent leaks during the storage time.

Separation

Materials contaminated with hazardous wastes are hazardous waste as well. Thus, it is a good strategy to separate hazardous materials from general waste. It is important to separate hazardous wastes into compatible groups. Separating them into practical groups also makes sense. For example, a supplier may give credit for return of a material for reprocessing. Therefore, mixing other materials with it may reduce its value. A mixed waste may increase reprocessing cost and difficulty.

Pretreatment

Pretreatment is any process that makes final treatment more economical, feasible or effective. The final treatment may not work for certain hazardous materials unless pretreated. Pretreatment may include any form of treatment and may involve several processes in sequence. It often involves separation and may reduce the variety, volume, or concentration of contaminates. One example of pretreatment is removal of oil from storm water runoff in parking lots. Holding tanks and skimmers, sludge pits, or other means can help extract the oil from the runoff water.

Detoxification

One form of pretreatment or treatment is detoxification. This method removes toxic characteristics from a material. There is growing interest in this capability. Biologists have found

microorganisms that perform this function. For example, researchers have identified a fungus that will digest dioxin, DDT, benzopyrene, and polychlorinated biphenyls.

Treatment

There are many kinds of treatment for wastes, which may involve physical, chemical, or biological processes. Treatments may include disposal methods. Certain methods work for specific wastes only.

Biological Treatments Biological treatments typically involve organic wastes. Microorganisms of various types, including bacteria, break down substances into alternate, more desirable forms. One form of treatment is composting, not suitable for all hazardous wastes.

Chemical Treatments Chemical treatment may include adjusting pH with acids or bases. It may involve extraction of oils, heavy metals, ion exchange, oxidation, and other techniques.

Physical Treatments Physical treatments primarily isolate or concentrate particular materials, reduce their volume, solidify, detoxify or perform some combination of these functions. For example evaporation can reduce volume, as can compaction. Adsorption may remove certain materials. Solidification processes mix liquids or slurries with stabilizing or binding agents to prevent leaching of materials when buried in landfills. Cementation processes appear useful for binding high concentrations of inorganics and heavy metals. Thermoplastic processes mix paraffin, bitumen, or asphalt with dried sludge wastes at elevated temperatures. Polymerization and encapsulation are other forms of solidification processes.

Disposal

There are three primary methods for waste disposal: burial in landfills, deep-well injection, and incineration. Laws and regulations often limit the methods available.

A problem for many communities is having sites or access to landfills within a convenient distance. Establishing a new site and finding a suitable location for a site are not always easy. The public near a site usually resists having a site in their neighborhood. Some locations have hauling contracts with sites several states away from their own state. Refer to Case 26-4.

Burial There are two kinds of landfills: conventional and secure.

Conventional Landfills Municipalities use conventional landfills for general waste because they are relatively cheap to operate. They also have a high potential for leaching of materials to the surface for runoff, lateral leaching into adjacent ground, and leaching into deeper soil. Leaching into deeper soils can contaminate aquifers and other underground sources of drinking water. Today, landfills must meet strict design standards. The standards help prevent leaching. Operating standards require daily covering of dumped materials. That prevents air pollution and scattering of materials by wind and animals.

Secure Landfills Secure landfills for hazardous waste must meet stringent standards of the EPA. A secure landfill must have an impervious clay base or an artificial liner. These features intend to contain any leachate. A drainage system around the landfill collects groundwater and prevents it from entering the landfill. Special designs and instrumentation monitor the drainage system and groundwater near and under the landfill for leachate.

Deep-Well Injection Today, EPA regulations generally ban deep-well injection. In deep-well injection, pumps move liquid wastes through pipes deep into the earth into porous rock formations or natural underground domes. Normally, the well depth is below any useful underground water sources. If there are suitable sites, deep-well injection can avoid transportation costs and processing costs.

Some deep-well sites have not been without problems. Layers of rock and soil above the disposal sites became contaminated. There are questions about the reliability of geological sites to seal adequately the waste from movement and the potential failure of piping leading to the deposit site. Many sites have not fully resolved effects of potential earthquakes, failures in overpressured sites and other problems. An EPA study reviewed the risks of deep-well injection disposal.[4]

Incineration For other than heavy metals and a few other forms of hazardous waste, incineration can be a safe method of disposal. Incineration processes must fit the kind of waste involved. Incinerators can produce heat and steam for other processes. Today incinerators must have scrubbers downstream of the combustion process to ensure that hazardous materials do not escape. Researchers continue to study combustion methods and methods for recovering any dangerous gases or particulates remaining from combustion. A major problem for incinerators is public acceptance. Few are under construction. People in communities that are potential sites for hazardous waste incineration plants frequently do not want such a facility in their neighborhood.

Manage Distribution

Effective management is another important control for hazardous waste. The Resource Conservation and

Recovery Act of 1980 requires that anyone who generates, stores, transports, or disposes of hazardous waste must obtain an identifying number. The waste generated, stored, transported, or disposed of must follow a manifest system. The manifest system allows tracking of the type and amount of hazardous material generated until completion of proper disposal. The procedure ensures that all parties in a hazardous waste chain know the disposal location and method. In addition, a producer needs to track purchase and receipt of hazardous materials and their storage and use.

Effective management includes analysis of risks involving hazardous materials and any hazardous waste produced. It includes comprehensive plans for processes and thorough documentation of procedures. It includes training plans and tracking of training completed. It includes economic analysis of hazardous materials and waste processes. It includes continually reviewing and auditing of the processes and identification of improvements and hazard reduction opportunities. See also Chapters 34 and 35.

27-4 LAWS AND REGULATIONS

It is impossible to list all the laws and regulations that affect waste management and disposal. They change constantly at federal, state and local levels. Some foreign laws and regulations are even more stringent than those in the United States. This section reviews selected federal laws and regulations that apply to hazardous waste.

Prior to the late 1990s, the United States led the legislation and regulation of waste and hazardous waste. Since then, the European Union and its member countries have enacted laws similar to those of the U.S. In general, more recent EU regulation of waste and hazardous waste have exceeded those of the U.S.[5]

Worldwide, hazardous waste and hazardous waste cleanup remain a significant issue in many countries.

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act of 1976 (RCRA) was the first major federal legislation on hazardous waste. It has undergone several updates since its beginning. In addition, the Environmental Protection Agency (EPA) has created numerous regulations[6] intended to implement RCRA and its focus on hazardous waste.

The act does not cover radioactive waste, which falls under the Atomic Energy Act of 1954. Later, the Uranium Mill Tailings Radiation Control Act of 1978 gave the EPA responsibility for cleanup of radioactive materials from inactive uranium processing sites. RCRA does not include water pollutants regulated by the Clean Water Act of 1972. Also excluded by RCRA were boiler fuel incinerators. Many industrial or commercial boilers recover heat energy from materials defined as hazardous wastes.

The main portion of RCRA dealing with hazardous waste (Subtitle C) contains eight sections.

1. *Section 3001.* This section requires the EPA to develop criteria for identification of hazardous waste materials. It also requires the EPA to develop a list of substances meeting these criteria. That list began to define hazardous waste.
2. *Section 3002.* The second section addresses record keeping, labeling, packing, and transporting of hazardous wastes. It creates the requirement for the manifesting procedures.
3. *Section 3003.* This section requires the EPA to develop regulations for transporters to ensure that hazardous waste does not endanger human health or the environment.
4. *Section 3004.* The fourth section requires development of regulations for hazardous waste disposal facilities.
5. *Section 3005.* The section requires the EPA to issue permits to all operators of hazardous waste disposal facilities. These permits specify the type and amount of waste and processes allowed for a particular site. They also state the methods of disposal for particular wastes.
6. *Section 3006.* The sixth section allows states to establish their own programs if they meet or exceed the EPA programs.
7. *Section 3007.* The seventh section requires inspection of hazardous waste sites and facilities.
8. *Section 3008.* The eighth section establishes civil and criminal penalties for violators of hazardous waste regulations.

1980 EPA Regulations

In 1980, the EPA completed final rules on compliance with RCRA. This chapter has discussed a few of these provisions. Most of the regulations deal with the estimated 20,000 large quantity generators (LQGs) of hazardous waste. LQGs are those producing 1000 kg per month or more of waste.

1984 Hazardous and Solid Waste Amendments

The original RCRA excluded from strict EPA regulations those small businesses generating less than 2200 lb (1000 kg) of hazardous waste monthly. In 1984, Congress changed the law to exclude small businesses producing less than 220 lb (100 kg) of hazardous waste per month. In 1986, the EPA issued regulations affecting about 175,000 small quantity generators (SQGs) who produce between 100 and 1000 kg per month. These generators produce about 800,000 metric

tons of hazardous waste per year, less than 0.5% of all hazardous waste produced in the United States.

Regulation of Underground Storage Tanks

Revisions to RCRA established controls for underground storage tanks. Many underground tanks store gasoline, petroleum products, and other substances. Some developed holes from corrosion and other factors and their contents leaked into the ground. The material migrated and contaminated ground water. This update to RCRA caused the removal of many unused storage tanks and tanks with designs that would not contain leaking materials. In addition, the standards established requirements for the design and use of new storage tanks that would prevent, monitor for, and remedy leaks.

Marine Protection, Research and Sanctuary Act of 1972

This act bans dumping of radioactive, biological, and chemical warfare wastes in the ocean. It requires permits for dumping of sewage sludge and dredged materials.

Medical Waste Tracking Act of 1988

This law established a two-year demonstration program for tracking medical waste from generator to disposal. Although the law included only a few states, others could volunteer to participate. The law requires EPA to establish regulations for medical waste generators, transporters and treatment, storage and disposal facilities. The agency is to monitor the program and report on results, costs, and benefits.

CERCLA (Superfund)

The problems of hazardous waste extend back many years. What to do with waste already disposed of also became a national issue. The result was the development of a Superfund. Contributions by both government and private industry created a source to cover the cost of cleaning up the worst of the many hazardous waste sites of the past. Industry contributed 75% of the initial $1.6 billion fund. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), passed in late 1980, took action to clean up some hazardous waste sites. The act also addressed liability. It stated that those causing or contributing to a release or threatened release from an inactive hazardous waste site shall have strict, joint, and several liability for cleanup, containment and emergency response activities at the site. Liable parties included generators and transporters of the waste and owners and operators of the disposal site.

Although CERCLA legislation expired in 1985, the 1986 Superfund Amendments and Reauthorization Act (SARA) reauthorized CERCLA.

SARA Title III

Another problem addressed by legislation was informing citizens who might be exposed to hazardous materials. This idea is called Community Right-to-Know. The Emergency Planning and Community Right-to-Know Act of 1986 (also known as SARA Title III) established the requirement to inform communities about hazardous materials. The act also authorized states to pass laws requiring emergency planning for potential hazardous material release events. Under these state laws, companies must prepare emergency response plans and make them available to authorities in communities around a plant. The planning requires coordination with local medical services, fire departments, police departments, and other officials. The purpose of coordination is to provide adequate time for people to protect themselves against the hazards of a release.

OSHA Regulations for Hazardous Waste Site Activities

As people began to clean up hazardous waste sites, workers faced dangers of exposure to unknown contaminants. Planning and management of cleanup activities must include the protection of workers. In December 1986, OSHA created interim final rules for Hazardous Waste Operations and Emergency Responses (HAZWOPER). It protects public and private sector employees involved in handling hazardous waste materials. The final rule went into effect in early 1989.[7] HAZWOPER standards include site analysis and control, training, medical surveillance, air monitoring, protective equipment, informational programs, decontamination procedures, and emergency response plans.

California Proposition 65

In November 1986, California voters overwhelmingly approved Proposition 65, which enacted the Safe Drinking Water and Toxic Enforcement Act. It requires that no business may expose people to chemicals that can cause cancer, birth defects, or reproductive harm without giving a clear and reasonable warning. One provision prohibits businesses from knowingly discharging such chemicals into the drinking water. However, a key provision of this law assigns an employer responsibility to prove his products and emissions are safe. If they are not, the employer must give public warnings. This is in contrast to normal tort procedure where the burden of the proof on harm rests with the employee or consumer.

Nuclear Waste Policy Act of 1982

Late in 1982, Congress passed the Nuclear Waste Policy Act (NWPA). It addresses the national problem of what to do with high level radioactive waste (HLRW), mainly spent nuclear fuel from nuclear power plants.

NWPA provisions involved protecting public health and safety and the environment, acceptance of waste for disposal, creating a repository of permanent disposal of spent fuel and high level waste, safe transportation of waste to the repository, interim storage of spent fuel for utilities, public participation in the nuclear waste disposal solution and costs recovered from waste generators. Establishing national waste sites for HLRW is not fully resolved.

The Department of Energy (DOE) is the agency responsible for most provisions of the act. DOE had responsibility to recommend three sites to the President. He was to recommend one site to the Congress. If Congress approved the recommended site, DOE was to build the national repository at that site. DOE was to select a second site also, but a repository was not to be constructed on it. In addition, DOE was to develop the transportation system for moving the waste to the site. Most HLRW remains stored at nuclear power plants where it is generated or in regional storage facilities.

The act created the Nuclear Waste Fund to finance the waste disposal program. Since 1983, the federal government has collected from nuclear utilities fees determined by the amount of electricity generated.

Beside HLRW, NWPA addressed other forms of radioactive waste. Included is low level radioactive waste (LLRW). There are many forms of LLRW. Some have significant radioactivity. Examples of LLRW are contaminated clothing, filters, resins, and metals from power plants, waste from medical treatment, laboratory radioactive waste, and other forms of waste with limited radioactivity.

Transportation Safety Act of 1974

Both the EPA and the Department of Transportation (DOT) have responsibilities related to transport of hazardous waste. All EPA hazardous wastes are hazardous materials under DOT regulations. Both agencies participate in the manifest system. As discussed in Chapter 14, DOT regulations address quantities, packaging, labeling, routes, shipping papers, incident reports, and training.

DOT publishes an extensive list of hazardous materials, called the DOT Hazardous Materials Table (HMT).[8] It provides the following data for each entry:

- symbol (quickly identifies certain requirements)
- hazardous materials' descriptions and proper shipping names
- hazard class or division
- identification number
- packaging group
- label codes
- special provisions
- packaging authorizations
- quantity limitations
- vessel stowage requirements

The Hazardous Materials Table falls under the responsibility of the Pipeline and Hazardous Materials Safety Administration (PHMSA) of DOT.

EXERCISES

1. Investigate the design, special features and design limitations for each of the following:
   (a) hazardous waste landfill
   (b) hazardous waste incinerator
   (c) high level nuclear waste repository
   (d) high level nuclear waste transport containers
   (e) deep-well injection facilities
2. Find out what plants or facilities in your community have emergency response plans. Obtain a copy of them and review them.
3. Find out if there are any hazardous waste sites in your area. Determine if any are on the Superfund National Priority List for cleanup or have been cleaned up.
4. Visit a hazardous waste generator, transporter or disposal site. Find out how they manage manifest requirements and what procedures are involved.
5. Contact a local manufacturing plant to find out how the company manages hazardous waste.
6. Contact a hazardous waste hauling company and obtain their current waste hauling and disposal fees.
7. Check with a university in your area to find out how hazardous waste is managed across the entire campus.

REVIEW QUESTIONS

1. Describe the hazardous waste problem in the United States.
2. What is a hazardous waste? What is RCRA hazardous waste?
3. What are the major dangers of hazardous waste?
4. What problems have contributed to the hazardous waste issues of today?
5. Describe the controls for hazardous waste. Characterize each. Which controls are most preferred?

6. Describe the process to reduce quantities of hazardous waste.
7. Briefly describe the role of each of the following in protecting the public against hazardous waste:
   (a) RCRA
   (b) Marine Protection, Research and Sanctuary Act of 1972
   (c) Medical Waste Tracking Act of 1988
   (d) CERCLA
   (e) SARA
   (f) SARA Title III
   (g) NWPA
   (h) HMT
8. What does HAZWOPER refer to?

NOTES

1 "Draft Report on Hazardous Waste Disposal in Erie and Niagara Counties, New York," State of New York, Department of Environmental Conservation, Interagency Task Force on Hazardous Wastes, March 1979.

2 www.ecy.wa.gov/beyondwaste/bwprogHW.html

3 40 CFR 261, subpart D.

4 www.epa.gov/ogwdw/uic/pdfs/study_uic-class1_study_risks_class1.pdf

5 David Vogel, *The Politics of Precaution: Regulating Health, Safety, and Environmental Risks in Europe and the United States*, Princeton University Press, Princeton, NJ, 2012.

6 40 CFR Parts 124, 260–268, 270, 271, 273, and 279 deal with hazardous waste.

7 *Federal Register*, vol. 54, No. 42: 9294–9336 (1989). 29 CFR 1910.120, Hazardous waste operations and emergency response.

8 49 CFR 172.101 (PHMSA/menuitem.6f23687cf7b00b0f22e4c6962d9c8789/?vgnextoid=d84ddf479bd7d110VgnVCM1000009ed07898RCRD&vgnextchannel=4f347fd9b896b110VgnVCM1000009ed07898RCRD)

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CHAPTER 28

PERSONAL PROTECTIVE EQUIPMENT

A hazard control mentioned in several previous chapters is personal protective equipment. There are many activities requiring personal protective equipment (PPE) as a primary control. In the "hierarchy of controls" concept (Chapter 9), PPE is the last resort if one cannot eliminate or manage hazards. PPE applies when other engineering and administrative controls do not work and hazards remain.

Sales of personal protective equipment exceeded $16 billion in the United States in 2015. There are many manufacturers and suppliers of personal protective equipment. There is no single directory of all PPE. One must search multiple sources to find proper and effective PPE.

Some PPE sales personnel become very knowledgeable in selection, use, and maintenance of PPE. Some PPE supplier associations[1] provide training for the important role PPE sales personnel provide.

28-1 GENERAL PRINCIPLES

Priorities

Personal protective equipment falls at the bottom of the list of priorities for controlling hazards. It is in the same priority class with procedures. Actually, its use is a procedure. Personal protective equipment is low in the priority list because it does not remove hazards. Personal protective equipment is low in the priority list because it requires user behavior. To be useful, PPE must be in place when needed.

In general, personal protective equipment creates a barrier between a hazard and a wearer. However, the hazards remain.

Employer Responsibility

Laws and regulations assign the responsibility for PPE to employers. PPE falls within the general concept that employers are responsible for providing employees with a workplace free of hazards. Employers are responsibility for the selection of appropriate and effective PPE. Employers are responsible for proper fit, maintenance, and cleanliness. Employers are responsible for management of PPE programs, employee training in proper use and knowledge of hazards requiring PPE, enforcement of use, and other details. Employers have these responsibilities even when employees own their personal PPE.

OSHA often issues citations to employers who do not operate a suitable PPE program. One study investigated factors involved when companies received a citation for non-compliance with the OSHA respiratory protection standards.[2] During the period from 1999 through 2006, OSHA inspectors issued 30,000 citations related to the respiratory protection standard.

Problems

Personal protective equipment is an essential protection for many hazards. However, PPE protection may not be sufficient. There are several factors that prevent PPE adequacy. One problem is effectiveness. One must have the right equipment for the hazard. Another problem is fit. Poor fit may result in inadequate protection. A third problem is use. Users must wear the personal protective equipment, even though the hazard it protects against is not always present.

Effectiveness For personal protective equipment to be effective, one must know the hazard. For example, some respirators only protect against gases or specific gases only. Other respirators protect against particulates and no gases. Some glove coatings may dissolve in the presence of certain solvents, but be effective for others. Some hazards are life-threatening. Others are not. The proper equipment requires careful selection for the hazards.

Fit For personal protective equipment to work properly, it must fit the user. People come in various sizes and shapes. For example, respirators that do not fit the face will leak and

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not achieve the protection desired. Fit testing is an essential part of respirator use.

Another example involves hard hats. Improperly adjusted hard hat suspensions can lead to injury if something strikes the hard hat. Also, acid suits and gloves that do not meet properly along the arm will expose skin to possible contact with spilled acid. Poorly fitted equipment may create discomfort and discourage use.

Women have traditionally had difficulty getting personal protective equipment that fits well. With the increasing number of women in hazardous jobs, the availability of sizes for women has improved.

Use Issuing employees personal protective equipment does not mean they will wear the equipment. Work rules and enforcement of them are important means of gaining user compliance. Training should include the hazards requiring PPE and proper use, maintenance, and cleanliness of PPE.

Feedback on PPE use increases use. For example, one study report gave wearers results of hearing tests following use and non-use of hearing protection compared to non-use. The results significantly increased wearing of hearing protection.

Worker acceptance is also an important factor in use. Workers need to participate in selection. Style and other choices as well as the chance to try different products and check their comfort will improve acceptance and use. Use of company logos or worker team logos can contribute to self-image and user acceptance.

Failure to wear PPE is a very common problem. There are few studies of the issue. One source[3] listed the following:

- 16% of workers who sustained head injuries wore hard hats and employers required 40% to wear them at specific locations.
- 1% of workers suffering face injuries wore face protection.
- 23% of workers with foot injuries wore safety shoes or boots.
- 50% of workers with eye injuries wore eye protective equipment.

Regulations and Standards

Various government organizations require the use of personal protective equipment. Agencies include OSHA,[4] MSHA,[5] and others. There are NHTSA standards for seatbelts in vehicles. The European Union has a comprehensive standard on PPE.[6] Implementation requires legislation by member countries.

There are several organizations that have recommendations and consensus standards on personal protective equipment design, performance and certification. NIOSH has numerous publications and reports on PPE.[7] ASTM has standards for testing personal protective equipment. ANSI has several standards for design, performance, use, and certification of personal protective equipment. SAE has standards for seat belts in various vehicles. Other organizations, such as the American Society of Safety Engineers, the American Industrial Hygiene Association, the Safety Equipment Institute and the International Safety Equipment Association participate in the development of voluntary standards.

Sources of Help

Several publications help buyers of personal protection equipment locate manufacturers and suppliers of PPE products. Some safety and health trade magazines offer buyer guides. Suppliers advertise in safety and health publications. In addition, many PPE providers exhibit at annual conferences of safety and health organizations.

There are some computer programs that help with selection of certain types of protective equipment. For example, proper fabrics and materials are critical for gloves, protective suits, and other PPE. Selection of respirators can become complicated. Some of the programs require inputs on use environment, activity, and other factors involved in the protected hazard. There are data banks that recommend protective equipment for particular hazards. The National Library of Medicine operates a resource called Chemical Hazards Emergency Medical Management (CHEMM).[8] The web site offers help with several functions, including PPE selection. Some manufacturers, insurance companies, and other organizations publish charts and guides for selection of personal protective equipment.

Requirements

In general, personal protective equipment should meet several principles.

- The equipment should not create additional hazards to the user.
- The materials of construction should hold up under reasonable use.
- PPE should withstand intended conditions.
- In some cases, PPE should be cleanable.
- PPE should be comfortable.
- Style and appearance are important for user acceptance.

User Involvement

Users should have involvement in the selection of personal protective equipment to foster acceptance and use. Users need to understand the hazards that create the need for the equipment and the dangers faced when not wearing the equipment. They need to learn the importance of the equipment in protecting them and to understand the rules related to

use enforcement. Users need training in proper use of equipment, proper care and maintenance. They need to know about testing equipment for fit and comfort.

Assuring Performance

Inspection User acceptance and use of personal protective equipment are essential for equipment performance. Other factors, such as regular inspection for condition and function, help achieve performance. There should be a management plan and process to track inspection and condition of all personal protective equipment.

Maintenance, Repair, and Cleaning There needs to be a maintenance and repair program. Personal protective equipment that is not in good condition or not properly adjusted for fit needs corrective action. Filters in respirators need regular replacement. Protective eye wear needs regular cleaning. Some items need disinfecting. Some need decontamination.

Replacement Equipment that is not in good condition need removal from use. Users should dispose of equipment intended for one-time use after use. One should not reuse disposable PPE. PPE that does not meet standards requires repair or replacement.

Testing Inspection may not be enough to determine performance of some personal protective equipment. Some equipment requires testing. For example, there are devices available to test respirator fit. Lifelines need periodic testing to make sure they can carry required loads.

Certification The buyer or user of personal protective equipment cannot always tell if purchased items meet published standards. There are certification programs for some equipment. NIOSH certifies the performance of some respirators. The Safety Equipment Institute is a not-for-profit organization that tests and certifies a broad range of industrial safety products, including personal protective equipment. Its certification is voluntary for manufacturers of products.

28-2 HEAD PROTECTION

Hazards

One danger to the head is falling or flying objects. Falling or flying objects can also strike the neck and shoulder area. In tight spaces, a worker may bump his head against something and receive an injury. Bureau of Labor Statistics (BLS) data show that only 16% of workers receiving head injuries were wearing hard hats.

There are also dangers of getting hair caught in machines or setting hair on fire. Sanitation rules may require preventing hair from falling into food. Clean room work requires that hair and skin particles not contaminate the work.

Types of Head Protection

Helmets There are a wide variety of helmets. Figure 28-1 shows two examples of head protection. Helmets vary in materials of construction and features. Some helmets can accommodate other protective equipment for eyes or hearing.



(a) (b)

Figure 28-1. Examples of (a) a helmet with visor and (b) a hood. (Photos provided by and reprinted with the permission of Mine Safety Appliances.)

CASE 28-1

A student helicopter crewman became eligible for in-flight training. He didn't have his own helmet, so he borrowed one. During his training flight, the helicopter had an accident. Investigators at the crash site found the fuselage resting on the student's helmet. The fuselage did not crush the helmet. However, the student died of strangulation because he was not wearing his chin strap properly. He had not received training in proper use.

Standards classify helmets into two groups. Type I, hard hats, have a continuous brim all the way around. Type II, hard caps, have only a visor brim in the front.

Different kinds and thicknesses of material used in helmets vary in the ability to prevent penetration of an object through the outer shell. Some materials for helmets have high dielectric properties and protect users who work around electrical lines and equipment. Metal helmet materials will conduct electrical current.

Helmet materials have ratings for weight, flammability, and water absorption properties. ANSI standards divide helmets into classes A, B, C, and D based on certain combinations of properties.

Helmets have headbands and suspension webs inside them. They are very important in preventing head injuries. This structure distributes forces from a blow to a helmet over a large area of the skull. This structure helps absorb the energy of a blow. Headbands and suspension webs inside a helmet require proper adjustment. There should be a 1 1/4 in. clearance between the helmet shell and the suspension. This prevents the helmet shell from striking the head during a blow.

For cold weather or sanitation reasons, many manufacturers offer liners and ear covers for helmets.

There are special helmets for firefighters, riot police, motorcyclists, pilots, and athletic activities. Each has special features and may have other standards for their design. For example, firefighters' helmets have extended brims at the rear to protect the neck from falling debris.

Hoods Hoods protect the head, face and neck from heat, flame, sparks, molten metal, liquids, dusts, and chemicals. The type of hazard dictates the degree of protection and the kind of materials needed. Hoods may include hard hat protection.

Bump Caps Bump caps are lighter in weight than helmets. Bump caps protect users from bumping their head on objects, not from falling objects. Bump caps are not substitutes for helmets. Many models accommodate eye protection, cold weather liners, and other protective equipment.

Soft Caps Soft caps protect users from sparks, open flames, heat, dust, and molten metal splashes. They contain fire-resistant fabrics and materials.

Hair Nets and Caps Paper, fabric, or net caps or covers prevent hair from falling into food. They keep items undergoing assembly from contaminants. They also prevent hair from getting caught in machinery. Beards may need similar protection.

28-3 EYE AND FACE PROTECTION

Hazards

Flying objects and particles, airborne dusts, splashing liquids, excessive light, and radiation may injure the eyes. People must have protection from these dangers. The same dangers may injure face or neck tissues. The dangers increase when materials are hot or can react chemically with human tissue.

Selection and use of eye and face PPE when a user already has corrective eye wear, such as glasses or contact lenses, is important. Impact injuries to eyes can occur in many off-the-job activities and in athletics. Protection is important in all activities where there are hazards to eyes.

Types of Eye Protection

Table 28-1 lists various eye and face protective equipment. The table is a guide for selecting protection for particular operations and hazards[9]. Other sources also provide guidance for selection.

Spectacles To prevent frontal impact injuries, frames and lenses of eye glasses should meet performance standards for safety eyewear. Lenses must meet specific criteria to earn the name safety lenses. Industrial standards for safety lenses are more stringent than those for safety lenses for home and recreational use. Some plastic and hardened glass lenses meet these specifications. Some materials withstand pitting, heat, and chemicals better than others. Shading in lenses can reduce glare. Spectacles suitable for welding and cutting must also have adequate radiation filtering in the lenses (see Table 28-2 and note 9).

Spectacles with Side Shields Where there is a danger of falling or flying particles entering the eye from the side, there

TABLE 28-1 Guidelines for Eye and Face Protection[a]

Source	Assessment of Hazard	Protection
IMPACT: Chipping, grinding, machining, masonry work, woodworking, sawing, drilling, chiseling, powered fastening, riveting, sanding	Flying fragments, objects, large chips, particles sand, dirt, etc.	Spectacles with side protection, goggles, face shields. See Notes 1, 3, 5, 6, 10., For severe exposure, use face shield.
HEAT: Furnace operations, pouring, casting, hot dipping, and welding	Hot sparks	Face shields, goggles, spectacles with side protection. For severe exposure use face shield. See Notes 1, 2, & 3.
	Splash from molten metals	Face shields worn over goggles. See Notes 1, 2, & 3.
High temperature exposure	Screen face shields, reflective face shields.	See Notes 1, 2, & 3.
CHEMICALS:: Acid and chemicals handling, degreasing, plating	Splash	Goggles, eyecup and cover types. See Notes 3 & 11.
	Irritating mists	Special-purpose goggles
DUST: Woodworking, buffing,	Nuisance dust	Goggles, eyecup and cover types.
	general dusty conditions	See Note 8.
LIGHT and/or RADIATION	Optical radiation	Welding helmets or welding shields. Typical shades: 10–14. See Notes 9 & 12.
Welding: Electric Arc		
Welding: Gas	Optical radiation	Welding goggles or welding face shield Typical shades: gas welding 4–8, cutting 3–6, brazing 3–4 See Note 9.
Cutting, torch brazing, torch soldering	Optical radiation	Spectacles or welding face shield. Typical shades: 1.5–3. See Notes 3 & 9.
Glare	Poor vision	Spectacles with shaded or special-purpose lenses, as suitable. See Notes 9 & 10.

[a]29 CFR 1910, Subpart I Appendix B. www.ecfr.gov/cgi-bin/text-idx?rgn=div6&node=29:5.1.1.1.8.9#ap29.5.1910_1138.

Notes:

1. Care should be taken to recognize the possibility of multiple and simultaneous exposure to a variety of hazards. Adequate protection against the highest level of each of the hazards should be provided. Protective devices do not provide unlimited protection.
2. Operations involving heat may also involve light radiation. As required by the standard, protection from both hazards must be provided.
3. Face shields should only be worn over primary eye protection (spectacles or goggles).
4. As required by the standard, filter lenses must meet the requirements for shade designations in 29 CFR 1910.133(a)(5). Tinted and shaded lenses are not filter lenses unless they are marked or identified as such.
5. As required by the standard, persons whose vision requires the use of prescription lenses must wear either protective devices fitted with prescription lenses or protective devices designed to be worn over regular prescription eyewear.
6. Wearers of contact lenses must also wear appropriate eye and face protection devices in a hazardous environment. It should be recognized that dusty and/or chemical environments may represent an additional hazard to contact lens wearers.
7. Caution should be exercised in the use of metal frame protective devices in electrical hazard areas.
8.Atmospheric conditions and the restricted ventilation of the protector can cause lenses to fog. Frequent cleaning may be necessary.
9. Welding helmets or face shields should be used only over primary eye protection (spectacles or goggles).
10. Non-sideshield spectacles are available for frontal protection only, but are not acceptable eye protection for the sources and operations listed for "impact."
11. Ventilation should be adequate, but well protected from splash entry. Eye and face protection should be designed and used so that it provides both adequate ventilation and protects the wearer from splash entry.
12. Protection from light radiation is directly related to filter lens density. See Note (4). Select the darkest shade that allows task performance.

is a need for side shields. For example, turning the head during grinding operations creates a danger of particles reaching the eye from the side. Depending on the size and type of particle, side shields may be solid material, perforated (for ventilation) or wire mesh.

Goggles Goggles protect the eye from flying particles, splashes, molten metal, heat and glare. There are many types, suitable for specific applications (see Table 28-1). Some activities need protection of close-fitting eye cups. Other forms of goggles protect wearers engaged in other activities. Ventilation openings help prevent fogging of goggles. However, ventilation openings should be suitable for the hazards present. The larger the holes, the greater the chance for particles to reach the eyes.

Goggles also protect prescription glasses that do not provide adequate protection themselves. Goggles used for welding and cutting must also have adequate UV and optical radiation protection (see Table 28-2). Goggles for use around lasers must have adequate protection for the energy and wavelength of the laser beam (see Table 28-3 and note 9).

Face Shields When pouring hazardous liquids, working with molten metal or performing similar activities, workers

TABLE 28-2 Filter Lens Shade Numbers for Protection Against Radiant Energy (OSHA Table E-2[a])

Welding Operation	Shade No.[b]
Shielded metal-arc welding:	
1/16, 3/32, 1/8 or 5/32 in. electrodes	10
Gas-shielded arc welding (nonferrous):	
	1/16. 3/32, 1/8 or 5/32 in. electrodes 11
Gas-shielded arc welding (ferrous):	
	1/16. 3/32, 1/8 or 5/32 in. electrodes 12
Shielded metal-are welding:	
3/32, 7/32 or 1/4 in. electrodes	12
5/16 pr 3/8 in. electrodes	14
Atomic hydrogen welding	10–14
Carbon arc welding	14
Soldering	2
Torch brazing	3 or 4
Light cutting, up to 1 in.	3 or 4
Medium cutting, up to 6 in.	4 or 5
Heavy cutting, 6 in. and greater	5 or 6
Gas welding (light) up to 1/8 in.	4 or 5
Gas welding (medium) 1/8 to 1/2 in.	5 or 6
Gas welding (heavy) 1/2 in. and greater	6 or 8

[a]www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=10665.
[b]Note: shades more dense than those listed may be used to suit the individual's need.

need protection of the face. A face shield has a large, transparent panel that extends over the front and sides of the face. A face shield should also extend below the face to protect the neck. A face shield alone is never adequate protection for the eyes. It requires eye protection in addition.

Welding Helmets Welding helmets protect the face against ultraviolet radiation, sparks and molten metal during electric arc welding. A welding helmet will have a window with radiation protection for the eyes (see Table 28-2).

Laser Safety Glass OSHA requires employees potentially exposed to laser beams to have laser safety goggles with adequate filtering capacity for the wavelength and intensity of the laser beams. Table 28-3 gives minimum attenuation requirements for various laser intensities.

TABLE 28-3 Selecting Laser Safety Class[a] (OSHA Table E-3[b])

Intensity, CW Maximum Power Density (W/cm^2)	Attenuation	
	Optical Density (O.D.)	Attenuation Factor
10^{-2}	5	10^5
10^{-1}	6	10^6
1.0	7	10^7
10	8	10^8

[a]Note: this table lists the maximum power or energy density for which adequate protection is afforded by glasses with shown optical densities.
[b]www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=10665;
29 CFR 1926.102(b)(2); see also 20 CFR 1926.54 for additional requirements for protection from lasers.

Aircraft pilots face the potential of exposure to laser beams from the ground by people engaged in criminal activity. Manufacturers may achieve ways to provide laser radiation protection in windshields or through other means.

28-4 HEARING PROTECTION

Hazards

As noted in Chapter 23, exposure to excessive noise will produce temporary or permanent hearing loss. The danger is a function of volume, frequency, and duration of exposures.

Types of Hearing Protection

There are two kinds of hearing protection devices (see Figure 28-2). Muffs fit over the ears to keep sound from entering the ears. Plugs of various types fit into the ear canal. In either case there must be a good seal between a device and the head or ear canal. Plain cotton plugs are not acceptable for hearing protection, since they have little sound reduction.

The Environmental Protection Agency has a noise reduction rating (NRR) and labeling standards for hearing protectors.[10] These standards provide a reliable way to rate hearing protectors. As noted, the performance also depends on fit. NRR applies to continuous noise and may not represent the noise reduction from impulse noise. A NRR of 10

CASE 28-2

March 13, 2009. An airplane mechanic was replacing a hydraulic actuator on the nose gear of an amphibious float. While removing some components, hydraulic fluid sprayed the mechanic in the face and eyes. He was wearing the required safety glasses. Without them, he would have experienced serious eye injuries.[a]

[a]www.fs.fed.us/fire/av_safety/promotion/accident_prevention_bulletins/IAAPB%20%2009-02%20-%20Personal%20Protective%20Equipment.pdf



Figure 28-2. Examples of (a) ear muffs and (b) ear plugs. (Photos provided by and reprinted with the permission of 3M Corporation.)

would have the effect of reducing the noise in an environment at 90 dBA to an equivalent of 80 dBA if the protectors fit properly. For frequencies below 500 Hz, it is necessary to adjust ratings. Manufacturers can provide performance data by octaves for their products.

Muffs Muffs are best for severe noise environments. Muffs are more effective for high frequencies than low frequencies. They have a cushion that fits against the head. There are various patented designs for attenuation. Some muffs can attach to helmets. Some manufacturers offer muffs with receivers and communication equipment built into them. That allows effective communication among workers equipped with the communication features. Some suppliers offer muffs made with high dielectric material for work around high voltage sources.

Plugs There are many types of ear plugs. Some are reusable. Others are disposable. There are custom molded ones derived from a mold created from the ear canal of a user. Some plugs have properties or features that adjust to the user. Plugs are more effective for high frequencies than low ones. Users will find some types of plugs more comfortable than others.

Combination For the most severe noise environments, a combination of both muffs and plugs will achieve the greatest protection and sound attenuation.

28-5 RESPIRATORY PROTECTION

Hazards

Respiration is essential to life. Lack of oxygen can produce syncope (fainting) or death. Excessive concentrations of certain gases and particulates can interfere with breathing. In addition, certain gases and particulates create health hazards if inhaled.

Types of Protection

There are two approaches to respiratory protection. One approach is to assure high quality air for breathing. Quality air has the right mixture of oxygen and inert gases and is free of contaminants. In some environments, it is necessary to clean the air so it has high quality and people do not inhale contaminants. If there are particulates in the air, filtering air can remove the particles and make air suitable for breathing. If there are undesired gases present, different techniques can remove them to achieve breathable air. Methods may include adsorbtion or chemically capturing undesired gases. The preferred method depends on the degree of danger, the type of gas, and the potential for failure of cleaning equipment.

There are many kinds of respirators. Each applies to different air quality conditions and work situations.

There are three main classes of respirators. One is a self-contained sources of breathable air. An example is a supplied air system carried by an individual. Usually there is a backpack that feeds clean air to a wearer's respirator. A second class is a supplied air system. It pumps clean air from one location to respirators worn by workers in a hazardous location. A third system involves air-purifying respirators that remove particulates and gases from inhaled air. Examples are respiratory protective equipment shown in Figure 28-3.

SCBA A self-contained breathing apparatus (SCBA) is a device that provide clean, breathable air to a user. Each user



(a) (b) (c)

Figure 28-3. Examples of respiratory protective equipment. (Photos provided by and reprinted with the permission of 3M Corporation.)

carries a system for personal use. The systems, usually back packs, have limited air supplies. Use times vary with the work load and associated breathing rate. There are two types: closed circuit SCBA systems and open-circuit SCBA systems. A closed-circuit SCBA device recovers oxygen from expired breath to extend the useable time. An open-circuit device does not recover expired air.

Hose Mask This is one form of supplied-air respirator. An air line provides breathable air to a user mask from a suitable source A hose mask with a blower makes breathing easier during inhalation, because the blower aids the air flow from the clean air line. The length of piping and/or hose determines the distance a user can move from the supply.

If the air line fails, a wearer must be able to escape unharmed without the supplied air respirator. This also limits the distance from a clean air source. For systems that compress or pump air to a user, it is necessary to remove any contaminants introduced by the system itself. A common contaminant is compressor lubricating oil.

Air-Line Respirator This is another type of supplied-air respirator. A system provides breathable air directly to a respirator through a hose. Breathing regulators match the wearer's breathable air demands.

Air-Supplied Suits and Hoods This type of supplied-air respirator directs air to the breathing zone of the user. It may supply a hood or a full body suit. The air may also provide cooling air to a full body suit.

Air-Purifying Respirators These devices remove particulates and gases. They can have a full face piece, which covers the mouth, nose, and eyes. Some have a half-mask, which covers only the nose and mouth. Some are mouthpiece respirators, which cover the mouth only and require users to wear a nose clip to prevent inhalation through the nose.

Canisters or Chemical Cartridge Respirators This is one type of air-purifying respirator. Breathing air moves through a container that removes gases or vapors. No single built-in process removes all types of hazardous gases or vapors. Most canisters remove one specific gas contaminant. Some are effective only for certain concentrations of a gas.

Table 28-4 lists the color coding of canisters. Canisters must have labels that state what gases and gas concentrations they handle. Because contaminants and concentrations in an environment can vary with time, use of canister respirators needs careful application.

Filter Respirators Filter respirators remove particulates through mechanical filters. There are filters for specific types and sizes of particulates. Some filter respirators are disposable. For some, one can change filters. Filter respirators do not protect against gases and vapors.

Escape Respirators People may work in areas that are free of contaminants. However, a leak in a system may produce dangerous breathing atmospheres. In such situations, escape respirators issued to workers provide protection for the danger for a very short time. Workers have time to leave the contaminated area. Escape respirators are not for general use. There must be sensors to detect and warnings to alert workers to a release of contaminants.

TABLE 28-4 Color Codes for Gas Mask Canisters[a]

Atmospheric Contaminants to Be Protected Against	Colors Assigned[b]
Acid gases	White
Hydrocyanic acid gas	White with ½ in. green stripe completely around the canister near the bottom
Chorine gas	White with ½ in. yellow stripe completely around the canister near the bottom
Organic vapors	Black
Ammonia gas	Green
Acid gases and ammonia gas	Green with ½ in. white stripe completely around the canister near the bottom
Carbon monoxide	Blue
Acid gases and organic vapors	Yellow
Hydrocyanic acid gas and chloropicrin vapor	Yellow with ½ in. blue stripe completely around the canister near the bottom
Acid gases, organic vapors, and ammonia gases	Brown
Radioactive materials, excepting tritium and noble gases	Purple (Magenta)
Pesticides	Organic vapor canister plus a particulate filter
Multi-Containment and CBRN agent	Olive
Any particulates - P100	Purple
Any particulates - P95, P99, R95, R99, R100	Orange
Any particulates free of oil - N95, N99, or N100	Teal

[a] https://www.osha.gov/dts/shib/respiratory_protection.pdf.
[b]Gray shall not be assigned as the main color for a canister designed to remove acids or vapors. Note: Orange shall be used as a complete body or stripe color to represent gases not included in this table. The user will need to refer to the canister label to determine the degree of protection the canister will afford.

28-6 HAND, FINGER, AND ARM PROTECTION

Hazards

There are many hazards for hands, fingers, and arms. One hazard is hot or cold material and objects. Protection involves use of thermal insulation. Some operations may create fire or flame hazards for protective clothing. Where that hazard exists, protective clothing must be fire- and flame-resistant.

Another hazard is sharp objects and equipment. Examples are burrs and sharp edges on sheared sheet metal or metal objects. Another example is use of sharp knives and cutting tools. Other examples are axes and portable saws, such as chainsaws. Protective clothing, such as gloves, chaps and other clothing must be tough and resist cuts and tears.

Another hazard involves chemicals absorbed through the skin or creating potential tissue damage. Protective materials should not allow chemical penetration. A danger in medical situations is disease transfer through contact with patients' blood.

Another hazard is damage to skin from solvents or water that remove natural oils from skin and cause cracking. The exposures can be frequent or occur for long periods.

There are numerous other hazards which rely on protective clothing. Examples are bumping into sharp and pointed objects and radiation burns from welding and other activities. Loss of grip and slipping and dropping lifted items rely on clothing with slip-resistant properties.

When providing hand protection, selection of protective clothing should account for the tasks performed as well as the hazards. In some operations touch and feel are as important as the need for worker protection. Protective clothing must minimize any loss of touch.

Another hazard is electric shock. Sometimes protective clothing must provide electrical insulation.

Hands may reach into biological or radiation boxes through protective gloves. The material used in protective clothing must provide the needed protection.

Types of Protection

Gloves and Mittens Gloves and mittens cover the hands and fingers. When selecting hand protection, analyze the tasks performed, hazards, and materials posing the hazard. Then select the proper material and style of gloves or mittens. Most manufacturers produce their hand protection in a wide range of materials. Many publish guides or give direct help for making selections.

Some types of gloves protect the fingers. Some are fingerless and protect the hand. Some extend protection to the wrist and lower arm. There are gloves resistant to solvents, water, acids, caustics, salts, fats and greases, detergents, cuts, and abrasions. Some gloves have linings made from cotton or other material for comfort and to reduce sweating. Some contain lead to shield X rays and other forms of radiation. Leather gloves stop sparks and molten metals found in welding and foundry operations. Some gloves have steel or other metal mess for meat cutting operations.

Pads When baking at home, people use hot pads to remove hot pans from an oven. Workers in bakeries, foundries, and

other hot processes may prefer pads over gloves. Some pads hang from the wrist to assist with quick changes from hot work to work with unprotected hands.

Finger Guards and Cots Finger guards or cots cover an entire finger or a portion of a finger. They provide protection in operations where some fingers need protection and workers do not prefer full gloves.

Sleeves When protection must extend over the arms, workers may need special sleeves. Sleeves may cover the wrist and forearm only. Some extend to the elbow or to the shoulder. Some have gloves and mittens attached. Like gloves and mittens, there is a wide range of materials for sleeves.

Creams and Lotions Lotions and creams provide some protection to hands and fingers from water, solvents, fats, irritants, and other substances. Lotions and creams can replace skin oils, soften chapped skin, and kill germs. Where severe exposures occur, protective gloves prove more effective.

28-7 FOOT AND LEG PROTECTION

Hazards

Falling objects create a major hazard for feet. There are hazards also from slipping. There are hazards from stepping on protruding nails or objects and from hot materials, wet materials, and contact with chemicals. There are also cutting hazards of tools, such as axes and chainsaws. There are dangers from cold exposures and from hot work.

Appropriate footwear and clothing for the legs can prevent many injuries. BLS analysis shows that in 75% of foot injuries, workers were not wearing safety shoes.

Types of Protection

Safety Shoes Standard safety shoes (see Figure 28-4) have steel toes or toes containing crush-resistant materials. Safety shoes must meet certain standards. The standard calls for testing to demonstrate withstanding a 75-lb impact load and a 2500-lb compression load. Manufacturers offer safety shoes in many styles. Some come as boots.

Steel-toed shoes can sometimes create a hazard. Exposure to heat may store enough heat in the steel toe plate to cause thermal burns to the toes.

Metatarsal or Instep Guards For work involving heavy objects, one can attach metal guards that extend further over the foot rather than just over the toes. These are metatarsal or instep guards (see Figure 28-4 b).

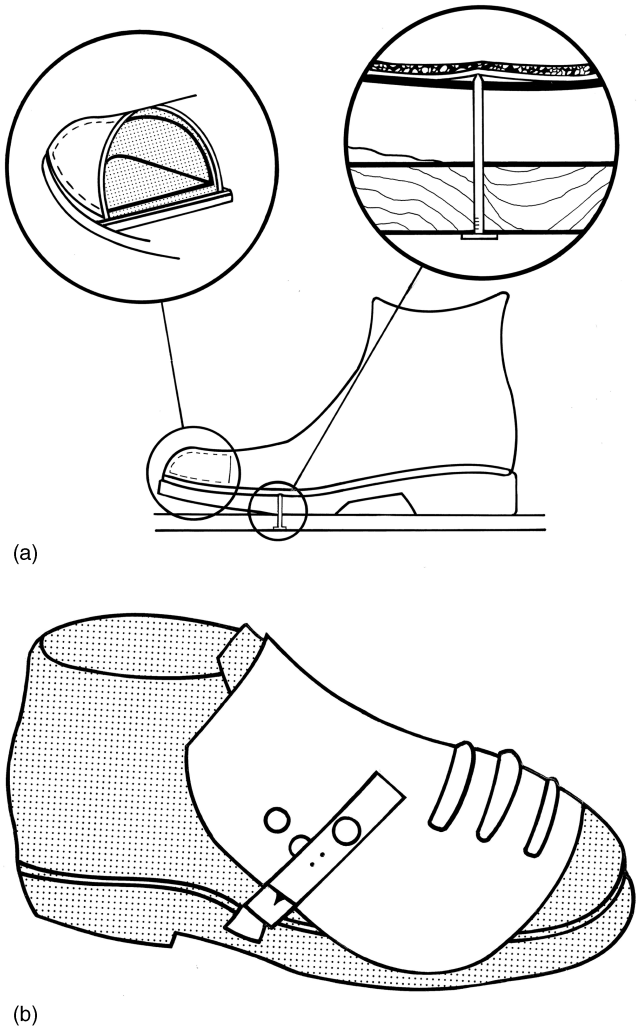


Figure 28-4. Foot protection: (a) Exploded view of a safety shoe with safety toe and instep protector and (b) metatarsal guard.

Steel Insoles Some work in construction or other settings pose a danger of stepping on sharp objects. Some objects, such as nails, can penetrate the sole of a shoe. Some shoes offer protection from penetrating objects with insoles made from metal or other tough material.

Rubber or Plastic Boots There are rubber and plastic boots in various styles for work with wet and muddy processes and exposure to chemicals. They may be ankle high or extend over the entire thigh. Some workers need waist- or chest-high boots for protection.

Protection from Cold or Hot For those who work in the cold, there are insulating insoles and electrically heated insoles. For those who walk on hot surfaces or face the danger of splattered molten metal from welding or

foundry work, there are shoes with insulation or insulated soles.

To provide for quick removal, some foundry shoes have quick release closures. The tops of foundry boots fit snugly around the lower leg to prevent any hot material from dropping into the shoes. The quick release feature allow a wearer to escape from hot material that may get inside a shoe.

Shin Guards There are padded shin guards for operations with potentially falling or moving objects. The guards use metal, plastic, or other materials.

Leggings and Leg Protection There are leg protective panels and chaps for loggers and others who work with chainsaws, piked poles or axes. The protection may also cover the sides and tops of feet and sides of the lower legs. The fabrics may have metal mesh, ballistic nylon or other materials.

Conductive Soles and Non-sparking Shoes People who work in hospital operating rooms where there is a danger of fire or explosion from flammable gases may wear conductive shoes. The shoes contact a conductive floor to prevent static charge buildup.

Spark-resistant shoes have no metal parts in them other than a steel safety toe built inside the structure. Because there are no shoe nails holding the soles in place, it is not possible for a shoe to create a spark that causes an explosion in a combustible atmosphere.

Nonconductive Shoes People who work with high voltage electrical equipment can get shoes with electrical insulation. They prevent electrical shock and the potential flow of current through the shoes.

Slip-Resistant Soles There are many surfaces where workers may slip and fall. The combined properties of two interfacing materials of shoes and floors can provide friction and prevent slipping. Proper shoe soles play an important part in preventing slips.

28-8 BODY PROTECTION

Hazards

Some hazardous materials and biohazards require use of body protective clothing. Work in confined spaces may also require special clothing for the body, because environments do not support life or there are dangers from fire and heat sources. Exposure may involved liquid, dust, mist, and other forms of contaminants. In many cases, conditions require protective clothing for the body and other PPE.

Body suits create sealed environments within them that require cooling and removal of moisture. Cold environments require extra clothing. Firefighters need heavy clothing to protect them from falling debris and flames.

Wearing additional clothing also adds to energy expenditure. The hazards of heat stress may increase. It simply takes more energy to move the extra clothing compared to normal clothing assemblies.

Work in explosive environments require static-free materials. It is difficult to clean some body clothing. Disposable PPE is much easier to manage. Workers may track contaminants to other areas and even to their homes unless the person removes contaminated body clothing at the work site.

With fully enclosed body suits, not only is there a need for cooling, there is a need for breathable air.

Types of Protection

Coats and Smocks Coats and smocks extend to the knee or below. They create a barrier for spills of various substances reaching personal clothing or skin. Depending on the fabric used, the coat or smock may be suitable for splatter of water, acids, oils, solvents, or other materials. The coats and smocks may be collected and cleaned for reuse or disposed of following use.

Coveralls Coveralls extend over the arms, body and legs. Some have hoods and boots. Coveralls may find use in clean rooms or to provide greater protection than coats or smocks. Most coveralls are one-piece garments. Some users prefer two-piece garments (pants and shirt or jacket) for some applications.

Aprons Aprons cover the front of a person from the upper chest to below the knees and may protect against splatters of hazardous substances, molten metals, oils, greases, or other materials. The type of hazard determines the kind of fabric and coating appropriate. Leaded aprons prevent radiation from reaching the body of the wearer. Their weight may interfere with some tasks.

Full Suits Full body suits provide protection when substances create a danger to life or may cause immediate or latent health problems. A full body suit provides a barrier between the danger and the user. Work in water may require insulation because of rapid heat loss. Diving gear in cold water may require a supply of heat.

For some serious hazards, the integrity of the clothing creating a barrier is important. Tears or holes may allow contaminants inside the suit. Poor fit between coat and pants or coat and gloves can leave skin open to dangerous materials. Users of full body suits need breathing air, cooling, and moisture control. There are special suits that provide protection in radioactive and biohazard environments.

Fire Entry and Proximity Suits People may need to approach or enter burning locations for rescue or critical tasks. They need insulation from the heat. There are two kinds of suits for fire. One is a proximity suit. It allows a wearer to approach a fire. The other is an entry suit. It permits walking within the fire itself. An entry suit has heavier insulation than a proximity suit. Both suits have limited use times. Users of either may need their own air supply to provide breathable, cool air.

Many proximity and entry suits use aluminum-coated fabric to reflect radiant energy and slow the rate of heat transfer from the fire. The insulation and outer suit fabric are noncombustible or made from fire-resistant materials.

Use of these garments requires planning. Users and supporting personnel must know how long someone can wear the garments in hot conditions. Users must exit the conditions before getting local or general burns.

Cooling As noted in Chapter 18 in the discussion of heat stress, it is necessary to remove the heat produced from metabolism or the body temperature will rise. The metabolic cost of an activity may double when someone wears protective clothing. The environment within a closed suit will limit heat removal from the wearer. If someone wears a suit for more than 15 or 20 min., cooling can be important.

One way to provide cooling within a suit is to pump cool, breathable air into the suit and distribute it before exhausting it to the surround. There are self-contained refrigeration or air conditioning units available for full body suits. Also, there is special underwear with small tubes that allow coolant to flow to legs, arms, and body.

There are also vortex coolers. Compressed air passes from a tube or pipe into a chamber that causes the air to spin in a vortex. The temperature of the air along the outer surface of the vortex drops as a result of rotation. Bleeding off the outer air can provide a significant amount of cooling capacity with little cost.

There are air- and water-cooled helmets. A very large portion of the body's blood flow goes to the head and brain. Studies have shown that cooling the head alone can remove a large amount of heat from the body.

Rainwear Another kind of personal protective clothing is rainwear. There are many people who must work in wet, outdoor conditions. Wet clothing will increase body cooling. Rainwear keeps users dry. For rainy, cold weather, there may be a need for insulated rainwear.

High Visibility Clothing Road construction and other work areas, such are parking lots, and traffic patrol locations, create hazards. Vehicles may strike people performing those jobs. There are luminescent orange vests, arm bands, and jackets that help make them visible.

Joggers, emergency workers, and others who are not very visible to vehicles at night can wear reflective stripes on clothing and shoes. Visibility is important so drivers have time to react and avoid hitting someone.

Personal Flotation Devices For activities around or on the water where there is a danger of drowning, people need personal flotation devices. There are several types of personal flotation devices, including jackets and vests. The U.S. Coast Guard has standards for personal flotation devices (PDFs).[11]

Puncture-Resistant and Cut-Resistant Clothing Police, security personnel, bomb squads and others need protection from ballistic objects. Body armor clothing provides this protection.

Workers using chainsaws need protection from chains potentially cutting through clothing. For these hazards, there are fabrics that resist severe cutting and shearing.

Workers in meat cutting operations need protection from powered saws, slicers, knives, and other cutting equipment. Clothes made from woven metal fabric give them some protection.

28-9 FALL PROTECTION

Hazards

Chapter 11 discussed the dangers of falls. There is a variety of fall protection devices available. Figure 28-5 provides some examples. Most fall PPE interrupts falls in progress. Because they must interrupt a body in motion, the devices must withstand certain loads prescribed by standards.

Types of Fall Protection Equipment

Components There are several components that form a fall protection system. Together they prevent or limit falls. The person who might fall wears a safety belt or safety harness. Standards limit the deceleration force for body belts to 10 times the force of gravity or less. Higher stopping forces are likely to cause injuries. For a full-body harnesses, the deceleration limit is 35 times the force of gravity. Body harnesses distribute the stopping forces more effectively and reduce the likelihood of injury from the stop.

Each body belt and harness has a D-ring. It is a metal loop shaped in the form of a D attached into the construction of the belt or harness. A lanyard or lifeline attaches to the D ring. The lanyard or lifeline requires a secure anchor at the opposite end. Lifeline anchors must be independent of any scaffolding or structure a person is on.



Figure 28-5. Example of a fall protection harness. (Photos copyrighted by and reprinted with the permission of Klein Tools, Inc.)

Safety belts or harnesses and lifelines are used to rescue people from confined spaces, grain bins or similar locations. Those entering such locations must have fall protection. With a lifeline a rescuer can retrieve an incapacitated worker without entering the same location and endangering himself or others.

Safety Belt There are several classes of belts worn around the waist for fall protection. Safety belts are useful for very short falls. The longer a fall, the greater the arresting force when one reaches the limits of a lanyard or lifeline. The longer a fall, the greater the likelihood of injury from the sudden stop. Many prefer a safety harness to a safety belt to reduce the potential for injury.

Window washing safety belts have special fittings that attach to anchors that are integral in the window units of a building.

Safety Harness There are several types of safety harnesses. One style has a belt at the waist and a harness over the chest and shoulders. Another style has additional loops that support the upper legs. A third style has a sling support that forms a seat, but it is not intended as a fall-arresting harness. Compared to safety belts, harnesses distribute the forces over a greater portion of the body. Therefore, harnesses are less likely to cause injury from an arrested fall.

Lanyard. A lanyard is a short, flexible rope or strap that connects a safety belt to an anchor point or a grabbing device on a lifeline. Lanyards must be ½ in. nylon rope or equivalent, have a static load capacity of 5,400 lb[12] and not have a fall distance greater than 6 ft. Some lanyards have designs that absorb energy in arresting a fall, thus reducing the impact load on a person.

Fall-Arresting Hardware All hardware must be free from sharp edges and withstand 4,000 lb static loads (see note 12). The most common hardware are D rings on safety belts and harnesses and snap hooks on lanyards.

Grabbing Device A grabbing device connects a body belt or lanyard to a lifeline. Some grabbing devices move freely along a lifeline when there is no load, but when there is a sudden load or movement, they lock onto the line. Some fixed ladders have grabbing devices that lock quickly if a climber falls.

Lifeline A lifeline is a rope that extends from an anchor point to a body belt, harness or lanyard. The anchor point and lifeline require a capacity for a 5,400 lb static load (see note 12).

Fall Arrester There are several patented fall-arresting devices. These devices are part of a lanyard. They create a controlled deceleration force while stopping a falling person.

Climbing Safety Systems Workers climbing fixed ladders or poles need protection from falling. There are patented systems that attach permanently or temporarily to ladders on towers, bridges, antennas, or other equipment. A safety belt or harness worn by a climber connects to the climbing safety device. If a person falls, the device locks and stops the fall.

Safety Nets Safety nets are not personal protective equipment because workers do not wear them. However, for workers involved in construction or bridge work, safety nets may be an important form of fall protection equipment. They do not replace lifelines and related fall protection equipment.

28-10 ELECTRICAL WORKER PROTECTION

People who work around electrical equipment face the danger of current flowing through them. Their personal protective equipment has a special requirement for electrical insulating properties. OSHA has standards[13] for special personal protection equipment. Other personal protection equipment for those working on electrical equipment is non-conductive hard hats, shoes, and clothing.



(a) (b)

Figure 28-6. Examples of a safety shower (a) and safety eye wash fountain (b). (Photos provided by and reprinted with permission of the Bradley Corporation, Menomonee Falls, WI.)

28-11 EMERGENCY SHOWERS AND EYE WASH FOUNTAINS

Hazard

Time is critical when responding to a spill of certain chemicals on the body or in the eyes. Flushing the affected area quickly with a lot of water will dilute or remove the dangerous substance and minimize injury.

Types of Equipment

There are three devices placed within easy access of areas where there are activities with dangerous substances. These devices are emergency showers (Figure 28-6a), eye wash fountains (Figure 28-6b) and eye and face wash fountains. OSHA requires these devices for work areas, but does not specify exact locations. ANSI standards gives detailed requirements for design and location of these devices. Periodic testing will assure that the equipment meets standards.

One should review location and signage periodically because operations change. Signage helps a victim or a co-worker to locate the needed device. Signage may become defaced, damaged, or removed.

Emergency Showers An emergency shower is a unit that floods a person's entire body after tripping an actuating valve. Most emergency showers have permanent connections to water lines to assure an unlimited source of water. There are also portable units that have limited water supplies. They provide at least 15 min. of flooding.

An emergency shower should be no more than 10 s away from potential users. Note the distance definition is in travel time. The location requires clear identification with signs and markings. In a spill emergency, no one should waste time looking for the shower. In some locations showers need protection from freezing. If conditions can make the water very cold, keeping it heated will make it comfortable for use.

Emergency Eye Wash Fountains. Eyewash fountains send two streams of water upward directly into each eye as someone bends over the fountain. An emergency shower cannot flush the eyes as well because the flow is downward. There are both fixed and portable eyewash fountains. Fixed units have unlimited water supplies. Portable ones deliver a required flow rate of 1.5 1/min for 15 min. The fixture has room for holding both eyelids open to the streams of water. The control valve does not require a hand to hold it open.

Fountains must be convenient to locations where there are dangerous materials. There should be clear signs and markings. Someone with eye injuries has impaired vision.

Emergency Eye and Face Wash Fountain Emergency eye and face wash equipment floods both the face and eyes at the same time. These devices have higher water flow rates than an eye wash fountains. Other design, location and marking standards are similar.

EXERCISES

1. A person wearing fall protection falls and a fall-arresting device and lifeline interrupt the fall. The person weighs 185 lb and the arresting force is 1,263 lb. What G load does the person experience? Does this exceed the recommended limits for fall arresting equipmen?
   (a) if the person wears a safety belt
   (b) if a person wears a safety harness
2. Obtain literature, including performance and cost, on hearing protection devices. Assume the employer considers providing disposable plugs every day, reusable

plugs every two weeks or muffs once every six months. If the workplace requires a noise reduction of 15 dBA, find out which form of ear protection will meet this sound reduction and which is most economical.

3. Select a job or operation, each having one of the following hazards:
   - **(a)** fall from a roof with a 5/12 pitch
   - **(b)** asbestos removal from community schools
   - **(c)** dishwashing operation in a major restaurant
   - **(d)** work in an operation where acid may splatter
   - **(e)** removal of steel parts by cutting torch from an old, cylindrical container that is 12 ft high and 6 ft in diameter and has a 30 in. access hole in the top

   Recommend personal protective equipment for these activities.

REVIEW QUESTIONS

1. Where does personal protective equipment fall in the priorities for control of hazards?
2. Does personal protective equipment remove hazards?
3. What are three important problems in the use of personal protective equipment?
4. Where does one find standards for personal protective equipment?
5. Where can one get help in selection and application of personal protective equipment?
6. How can one achieve performance of personal protective equipment? How can one get employees to wear PPE as directed?
7. Briefly describe the functions and characteristics for each of the following:
   - **(a)** helmet
   - **(b)** bump cap
   - **(c)** hood
   - **(d)** hair nets and caps
   - **(e)** spectacles
   - **(f)** side shields
   - **(g)** goggles
   - **(h)** face shield
   - **(i)** welding helmet
   - **(j)** laser safety glasses
   - **(k)** ear muffs
   - **(l)** earplugs
   - **(m)** self-contained breathing apparatus
   - **(n)** supplied-air respirators
   - **(o)** air-purifying respirators
   - **(p)** canisters
   - **(q)** sleeve
   - **(r)** finger cots
   - **(s)** safety shoes
   - **(t)** steel insoles
   - **(u)** leggings
   - **(v)** non-conductive shoes
   - **(w)** aprons
   - **(x)** full-body suits
   - **(y)** fire entry and proximity suits
   - **(z)** high visibility clothing
   - **(aa)** puncture-resistant and cut-resistant clothing
   - **(bb)** safety belt
   - **(cc)** safety harness
   - **(dd)** lanyard
   - **(ee)** grabbing device
   - **(ff)** fall arrestor
   - **(gg)** lifeline
   - **(hh)** climbing safety system

NOTES

1 Safety Equipment Institute - SEI (http://www.seinet.org) and International Safety Equipment Association ISEA (www.safetyequipment.org)

2 www.bls.gov/opub/mlr/2013/article/using-osha-inspection-data-to-analyze-respirator-protection-program-compliance-1.htm

3 https://ehs.okstate.edu/training/oshappe.htm

4 29 CFR 1910 Subpart I (General Industry; 29 CFR 1926 Subpart E (Construction).

5 30 CFR.

6 http://ec.europa.eu/growth/sectors/mechanical-engineering/personal-protective-equipment/index_en.htm

7 www.cdc.gov/niosh/topics/protclothing/default.html

8 http://chemm.nlm.nih.gov/ppe.htm

9 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=10665

10 40 CFR 211 www.gpo.gov/fdsys/pkg/CFR-2003-title40-vol22/xml/CFR-2003-title40-vol22-part211.xml

11 www.uscg.mil/hq/cg5/cg5214/pfd-lights.asp

12 29 CFR 1926.104 www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=10667&p_table=STANDARDS

13 29 CFR 1910.137 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9787

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CHAPTER 29

EMERGENCIES AND SECURITY

This chapter discusses emergency situations. It also covers fundamentals of security. The two have similarities. Both topics involve risk and risk management, covered in Chapter 34.

29-1 INTRODUCTION

Disasters and emergencies fill the pages of history. There are lessons learned from the burning of Rome, the great Chicago fire, the Johnstown flood, the Three Mile Island incident, the Bhopal tragedy, World Trade Center events of September 11, 2001, the tsunami in Japan on December 26, 2004, and many other events. The lessons caused changes in standards, codes, and laws. They caused changes in management systems. They caused people to change their behaviors and practices.

An *emergency* is any event that (a) happens suddenly; (b) disrupts the routine of an organization or community and affects its ability to function normally; and (c) requires immediate action.

A *disaster* is an emergency that results in multiple injuries or deaths and produces major property damage.

No one can completely avoid emergency situations. Emergencies can occur anywhere and affect anyone. One can prevent some emergencies, but not all.

Emergencies have lead times. A lead time is the time between awareness of an emergency or impending emergency and an emergency's actual occurrence. For some there is reasonable time to act and prevent some losses. For other emergencies there is little or no time to act before the emergency is underway.

There is at least one important problem for every disaster and emergency situation. It is what to do when such an event occurs. People must decide what to do and how to act. Their actions should help minimize the danger and losses. Quick and proper action can prevent unnecessary losses.

Knowing what to do depends on a lot of anticipation and planning. Part of anticipation is proper design that reduces losses as well.

29-2 TYPES OF EMERGENCIES

There are several types of emergencies. Some result from the forces of nature. Some involve fire and explosion. Some involve system failures. Some emergencies entail traffic or transportation problems. Some result from the behavior of people. For others, there are police, military, and public safety actions to assist people and protect property.

Natural Emergencies

Natural emergencies include floods, hurricanes, tornadoes, wind storms, snow, sleet, earthquakes, mud slides, avalanches, volcanic eruptions, and dust or sand storms. In some locations an insect infestation may create an emergency. Different locations face different emergencies. Table 29-1 lists examples of natural hazards.

Fire and Explosion

Chapters 16 and 17 discussed fires and explosions. Cases in previous chapters illustrate these kinds of emergencies. A fire in a hotel, theater, or other high occupancy facility may injure many people. Explosions can damage buildings far from the explosion site. See Case 7-1. Glass and other flying materials from an explosion can inflict injury on those nearby. Fires involving hazardous materials have caused the evacuation of entire communities. Fires in compressed air lines can lead to explosions.

System and Technology Failures

There are many kinds of system failures that can create emergencies. For example, interruption of operations may create hazardous conditions. Boiler overheating can cause dangerous conditions requiring quick action. Failure of temperature limit controls can lead to runaway processes. Failure of pressure limit controls can lead to rupture of pipes, gaskets, vessels, and other equipment. Sudden releases of steam, gas, fuel, or hazardous chemicals can create dangers

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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TABLE 29-1 Examples of Natural Hazards

Floods
Tornadoes
Hurricanes
Thunderstorms and lightning
Winter Storms and extreme cold
Ice storms
Extreme heat
Earthquakes
Volcanic eruptions
Landslide and mudslides
Avalanches
Tsunamis
Fires
Wildfires
Insect infestations

for plant personnel and surrounding communities. System failures may lead to fire and explosion.

Traffic Problems

Transportation accidents can interfere with traffic movement. Overturned tank trucks, multiple car accidents, and derailed railroad cars may block traffic for extended periods of time. If there are hazardous materials in a mishap, officials may need to clear or evacuate the area. Spilled materials may require proper treatment to prevent further disaster. For example, gasoline running into a storm sewer could lead to an explosion.

People Behavior and Workplace Violence

The behavior of people can lead to emergencies. Case 29-2 provides an example in which one person's irresponsible behavior affected thousands of individuals.

Some behaviors intend to cause harm. Some behaviors do not intent to produce emergencies. Strong feelings may lead to riots and mob behavior. Strikes and work stoppages sometimes lead to problems. Crowds rushing to sales when goods are in short supply can become difficult to manage. Crowds fighting for tickets to public events or pressing to enter auditoriums and stadiums have led to disasters. See Case 29-3.

There are episodes in which disgruntled workers or terrorists commit sabotage that leads to emergencies. A growing cause of injury and death at work involves workplace violence. Typically, employees or former employees attack or kill other employees or supervisors. Some of the cases involve depression and other mental illnesses unknown to employers. See Case 29-4.

Terrorist and Military Action

Military action in time of war creates emergency situations. Few military events occur in the United States. However, that is not the case in other countries. Terrorist activity often requires military support for police, firefighters, and emergency responders. At times terrorist activities occur in the U.S., creating large-scale emergency situations. The events of 9/11, 2001 in New York, Washington, DC, and Pennsylvania were terrorist-initiated. More recently, a widely publicized terrorist event involved bombings at the Boston Marathon in 2013 (see Case 29-5). Table 29-2 lists some types of terrorist threats.

It is not uncommon for military personnel to provide police and security roles. For example, when tornadoes strike communities and building debris creates opportunities for looting, states often call in the National Guard. The soldiers provide the manpower to help maintain public order and protect damaged property. In some situations, the soldiers

CASE 29-1

May 8, 1988, Hinsdale, IL. A fire broke out in the main switching room of a primary facility of Illinois Bell Telephone Company. It was one of the company's largest switching systems in Illinois, processing 3.5 million calls per day for 38,000 customers. Many customers were businesses and hospitals. The facility served two major airports. Because of the fire, even firefighters could not communicate with the power company and other responders.

Firefighters faced toxic fumes and electrical hazards that prevented use of water as an extinguishing agent. The hazardous smoke required evacuation of 300 residents within a five-block area. The loss of communications allowed the fire to intensify until someone turned off all electrical power to the facility two hours after the fire started.

The phone company used a priority scheme to restore telephone service to critical customers first. Many residents waited over two weeks to have their service restored.[a,b]

[a] http://articles.chicagotribune.com/1988-05-10/news/8803150844_1_new-exchange-telephone-exchange-switching
[b] http://telecom.csail.mit.edu/TELECOM_Digest_Online/1309.html

CASE 29-2

September 26, 2014, Chicago, IL. An employee of a contractor deliberately started a fire in a critical area of the Federal Aviation Administration's Chicago Air Route Traffic Control Center and then tried unsuccessfully to commit suicide. The fire destroyed critical communication equipment. The system enabled processing of flight plan data for a 91,000 square mile area in the Midwest and supported communication between controllers and aircraft.

The FAA implemented several contingency plans. One ensured that aircraft in the sky could land safely. Another allowed high altitude flights to continue uninterrupted through the controlled airspace. A third quickly moved Chicago personnel to other locations surrounding the Chicago-controlled airspace. The intention of their plans was to help maintain air traffic that the Chicago Center normally would have handled.

The outage lasted 11 days. It impacted U.S. national air traffic and some international flights.

Within 17 days, FAA and contractor personnel had completely rebuilt the destroyed communications equipment. The equipment rebuild involved 20 racks of equipment, 835 telecommunications circuits, and more than 10 miles of cable. The disruption cost airlines more than $350 million. It caused many inconveniences for travelers. It led to a thorough review of contingency plans and security risks. After studying the event, FAA implemented many changes to its emergency response plans.[a,b,c]

[a] www.aopa.org/News-and-Video/All-News/2014/November/06/ATC-Zero-Inside-the-Chicago-Center-fire
[b] www.npr.org/2014/09/29/352538409/chicago-air-traffic-control-fire-still-disrupting-flights-days-later
[c] www.faa.gov/news/press_releases/news_story.cfm?newsId=17834

CASE 29-3

April 16, 1989, Sheffield, England. Ninety-six people died at a British soccer match in Hillsborough Stadium. The standing room area adjacent to the field became overfilled with fans. The crowd pressed forward and pinned some fans against the 10-foot high fence that created a barrier between the fans and the playing field. Most of those who died were trampled or crushed against the fence so they could not breathe. Police at the event did not realize what was happening.

For many years, officials blamed the disaster on many of the victims, suggesting they were the cause of the disaster. However, a report issued more than two decades later determined that fans were not the cause. Police at an entrance suddenly allowed stadium access to a crowd trying to enter for the opening kick of the game. There was no control through ticket screening or for the number of people seeking entry. The fans ended up in the standing room area and overfilled the space. The delayed report led to a national apology to the victim's families.

The disaster led to changes in stadium designs and the management of fans entering stadiums.[a,b,c,d,e]

[a] http://articles.latimes.com/1989-04-16/news/mn-2494_1_soccer-game-crush-european-football-assns-ban-on-english-teams
[b] www.nytimes.com/2012/09/13/sports/soccer/britain-apologizes-for-blaming-victims-in-hillsborough-disaster.html?_r=0
[c] www.huffingtonpost.com/2012/09/12/http/www.huffingtonpost.com/2012/09/12/hillsborough-disaster-secret-papers_n_1876979.html
[d] www.youtube.com/watch?v=P_SmM9KuhIQ
[e] www.telegraph.co.uk/sport/football/teams/liverpool/10767715/Hillsborough-stadium-disaster-April-15-1989.html

CASE 29-4

March 24, 2015, French Alps. Germanwings Flight 9525 flying from Barcelona, Spain, to Dusseldorf, Germany, crashed into a remote area of the French Alps. All 150 aboard died in the crash.

The event was very unusual and involved a strange sequence of events. Evidence showed that the pilot was locked out of the cockpit. The only other occupant was the co-pilot. He overrode computer controls for the flight and deliberately set the plane into a steep dive that lasted about 8 minutes, ending in the crash.

Following the crash, evidence showed that the young co-pilot had wanted to be a pilot from his youth. The evidence also showed that the co-pilot had experienced depression. His physicians had issued a note excusing him from flying the day

of the flight. However, the co-pilot did not give the formal note to his employer. Some fear that he did not want to lose his job as a pilot. In the German medical system, physicians do not report medical findings to employers under rules protecting privacy.

Public discussion that followed challenged the procedures that prevent employers knowing about the mental health of employees. The concern was for those in roles with responsibility for the safety of others. Many question the ability to predict human behavior.

Lawyers will argue the legal aspects of the case for some time. Insurers of the flight have earmarked funds to cover their liability. Some blame the parent airline, Lufthansa, for not implementing a "two-person occupancy at all times" rule for cockpits.

Since the tragedy of 9/11 at the World Trade Center, many airlines have implemented a rule requiring two airline employees in the cockpit at all times. If a pilot or co-pilot must leave the cockpit to use the lavatory, another crew member must be in the cockpit until the person returns.[a,b]

[a]www.health.harvard.edu/blog/germanwings-flight-9525-shows-the-limits-of-predicting-human-violence-201504087855
[b]www.businessinsider.com/everything-we-know-about-germanwings-flight-9525-2015-3

CASE 29-5

April 15, 2013, Boston, Massachusetts. Two bombs planted by terrorists exploded among the crowd lining Boylston Street near the finish line of the Boston Marathon race. The bombs killed 3 people and injured 264. At least 14 people had limbs amputated because of the injuries from the shrapnel placed inside the home-made bombs.

Many rescue workers and medical personnel were in place for the race. The race involved thousands of runners and bystanders. These personnel attended to victims of the bombing.

Initially, police closed a 15-block area around the blast. To the extent possible, police cleared the streets of runners, fans, and onlookers. Authorities also restricted airspace over Boston, not knowing the extent of the attack. Phone connections were jammed by people trying to find their friends and family involved in the race or who ran from the scene in fear. Emergency groups set up a missing person operation to help match people disconnected by the events.

Police had difficulty collecting evidence at the crime scene because of the confusion. In the melee that followed, many people dropped backpacks and other bags. Authorities had to treat each as a potential bomb, a difficult task.

During the next four days there was a manhunt by several local, state, and federal police agencies. Identification of suspects emerged from various sources, including surveillance tapes. During the four days, police found two suspects. A shootout at the Massachusetts Institute of Technology campus resulted in the death of a campus policeman and one of the suspects. The suspects had hijacked a car and were trying to escape. Eventually, police located and arrested the second terrorist suspect. Investigations continued for some time. Later a jury convicted the second terrorist on 30 charges.[a]

[a]www.bostonglobe.com/metro/specials/boston-marathon-explosions

protect the public from entering an area in which additional harm might result.

29-3 PRIORITIES IN EMERGENCIES

The priorities when dealing with emergencies are universal.

Safety of People

When emergencies occur, the first priority is safety of people. The people may be employees, customers, visitors, or the public.

Caring for the Injured Care for those injured has the highest priority. That requires calling on those with knowledge and skill in treating injuries and illness. There may be medical personnel, EMTs (emergency medical technicians), and others trained in first aid or other response skills. An emergency situation with injuries will need bandages, patient handling equipment, and other items necessary for proper response and treatment.

Preventing Harm to Others Another part of actions to protect the safety of people is knowing what to do with those not injured. There may be a need for organized evacuation or

crowd management. Someone must lead these activities. It involves telling people how to proceed for their safety. It may include evacuation instructions and implementation of emergency exit lighting.

Preventing harm to others may require identifying and isolating dangerous areas. Someone must lead activities to clear the dangerous area. There may be a need to prevent people from entering the area or restricting access by the curious. The dangerous area may be a building, a site or a community. In some emergencies, gathering people into shelters protects them.

Completely different actions apply to different emergencies. Consider the different strategies between a fire and a tornado. In the case of a fire in a building, the usual action is to get people out. In the case of a tornado, it may be best to keep people inside in protected areas of the building.

Protection of Property

The second priority in an emergency is protection of property. This may involve turning off power, fuel or supplies to prevent further damage. It may require shutting down processes manually (see Case 17-2) or automatically to render them safe or to minimize loss of materials and products. Controlling and extinguishing fires will keep losses down. The proper actions depend on the kind of emergency and the kind of facility, process, or location. For example, if there is danger of a flood, creating dikes and sandbag barriers may prevent flooding of property.

Cleanup and Salvage

The third priority is cleanup and salvage. To make an area safe, someone must remove spilled hazardous materials. Fires sometimes leave building walls standing without support. They may collapse unexpectedly. A company may salvage and restore damaged equipment. In removing debris or rubble, careful action must prevent further damage or injury. Managing cleanup and salvage is a critical task. Communities struck by tornadoes often receive generous but misplaced help from volunteers. As a result, people waste resources and destroy salvageable items. Cleaning up damage to power, communications, and fuel lines can prevent further damage. Handling process cleanup and salvage may requires trained and qualified people.

Restoring Operations

The fourth priority is restoring operations and getting things back to normal. Companies or businesses will lose income and production until operations resume. Following an emergency someone must check the condition and safety of equipment. Some items will require repair. Startup procedures may require specialized leadership and skill. Case 29-1 and Case 29-2 illustrate the importance of managing restoration of operations.

29-4 PREVENTING LOSSES FROM EMERGENCIES

A primary objective when dealing with emergencies is preparation to initiate proper actions. The actions may involve company, community, medical, state, and other organizations and participants. Preparedness for emergencies involves several steps. One step is conducting analysis to identify potential emergency situations. Another is planning detailed responses and identifying participants and resources. Other steps include designing and implementing remedies that eliminate or reduce response deficiencies, training participants in proper implementation of plans, and prepositioning contracts or agreements for specialized equipment or personnel.

CASE 29-6

Community emergency management organizations have improved cleanup and salvage operations for tornado and wind damage to their communities. It is not uncommon for many volunteers to show up and help clean up the destruction. Someone needs to coordinate their activities.

One technique involves issuing permits to all individuals, including residents, entering a secured area where there is damage. The permit system provides some assurance that only qualified and screened individuals are in the area of damage. The method keeps out curious people and looters. Volunteers must register to assist at a central location before helping with cleanup.

Another technique is to provide cardboard boxes for those participating in cleanup activities. As they work through debris, the volunteers place anything considered of physical or sentimental value in a box. All boxes get marked for the fill location. The boxes get collected at a central location for evaluation by affected residents. The claimed items get listed on a log. Eventually, recovery managers dispose of unclaimed items.

Other organizing techniques help when managing cleanup and recovery process.

Regulations and Programs

Some federal regulations require preparation for emergencies. State and local requirements may supplement federal regulations. Regulations do not cover all emergencies.

Chemical Releases Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA) require chemical plants to develop emergency response plans. Title III, called the Emergency Planning and Community Right-To-Know Act of 1986, created state Emergency Response Commissions (ERCs) and emergency planning districts. Facilities subject to SARA Title III participate in local emergency planning processes. Each facility also submits material safety data sheets (MSDSs) or potentially Safety Data Sheets (SDSs) under the Globally Harmonized System to local and/or state elements. Each district completes and maintains an emergency plan.

In response to SARA Title III, the EPA developed the Chemical Emergency Preparedness Program (CEPP). The EPA modified and renamed this program to also focus on prevention of accidental releases.[1] The Federal Emergency Management Agency (FEMA) offers a range of emergency management resources.[2]

Radiological Accidents There are regulations involving several federal agencies (FEMA, NRC, EPA) and state and local governments about preparedness for radiation releases and accidents. Much of the emergency response responsibility of the federal government falls under the Department of Homeland Security.

The Planning Cycle

Several planning models exist for emergency management. The models emphasize that emergency preparedness is a continuous, ongoing activity. Figure 29-1 illustrates a four-step model that many organizations use. Other models are similar and vary somewhat in the main steps and their overall organization.

Note that actual emergency plans may include other tasks and resources, depending on the organization and the kind of emergency. The specialized descriptions that follow illustrate the planning cycle.

Step 1. Preparedness Preparedness includes measures aimed at getting an organization or community ready to react to any anticipated hazard or threat. It involves identifying potential hazards or threats, planning responses, conducting training, conducting drills or exercises, and educating employees and the public.

Some emergency management models call assessment the first step. Assessment focuses on identifying the possible hazards and threats. Assessment considers the likelihood and potential severity of a situation. It addresses factors involved in each type of hazard or threat. In the model discussed here, assessment is part of preparedness.

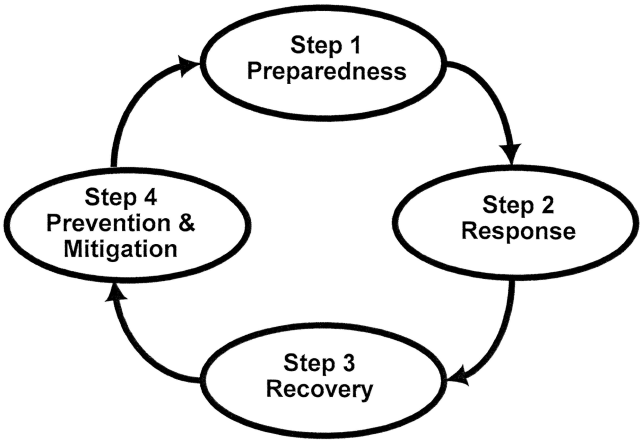


Figure 29-1. Major steps in a planning process for dealing with potential emergencies.

Planning During planning activities, leaders identify natural hazards, technological hazards, and terrorist threats, or workplace violence situations. Planning addresses the risks of each hazard or threat, including the likelihood of occurrence and the potential severity. Severity considers loss of life, loss or damage to property, injuries, business interruption, and other factors.

Planning also develops actions, policies, and procedures. That includes how to respond, identifying people, equipment, communication, and other resources and assigning responsibilities to organizational units and individuals. It addresses paths to recovery. Procedures include standard operating procedures for organizational units and individuals.

Planning may also develop contracts for equipment, specialized job skills and other resources needed during specific types of emergencies.

Establishing Command System and Communications One of the important parts of emergency planning is creating the command structure. Responding can be very dynamic. Someone must coordinate what gets done and where resources need to be. The situations may change rapidly. Coordination among police, medical, rescue, and many other resources is critical. Thus, there needs to be a command center with leaders of each capability in charge. There is a need for close coordination among the leaders.

Communication among the organizational units involved in a response and between a command center and field units must be in place. There needs to be communication capabilities that are not subject to destruction from the emergency itself.

Exercises Those who will serve during a response need to practice all aspects of an emergency. Many plans include situational exercises and drills. For example, a hospital may serve as the primary location for receiving and treating injured people. The staff must be able to handle the number of injured and identify which individuals get priority, a triage function. If a hospital cannot handle the potential number of cases, other medical support or additional hospitals may need to participate in executing an emergency plan.

Training All individuals who have roles in potential emergencies need training in their responsibilities. A response may require teamwork among individuals who do not normally work together. Responders need to understand the differences in responding to a variety of threats.

Education Beside training participants in the tasks they will perform, many will need to learn the overall impact on an organization or community. Many who normally serve in leadership roles need to understand how their roles may change.

There may be a need to build awareness across an organization or community about the potential of any threat and the potential severity. They need to know how a response plan will work.

Step 2. Response A response occurs when there is an actual emergency or an imminent one. Many emergency plans begin prior to an actual emergency. For example, weather forecasts often predict possible weather threats. The amount of lead time will vary. However, there is a need to create company or public alerts and to pre-position personnel and equipment so a response, if needed, is effective.

Warnings As noted, many weather conditions that create potential emergencies have significant lead times. Students in school, company employees, or responders need alerts to pending situation. They need to know if procedures will go into effect to minimize danger, prevent loss of life or property, and to ensure continuity of company or community operations. Warnings can take many forms. They may use radio, TV, social media, phone systems, alarms, or sirens. Many warnings become most effective when there is use of multiple warning methods.

Evacuation In some emergency events, there is a need to evacuate people from residences, workplaces, health care facilities, schools, or other locations prior to an event. Most vulnerable people are those without transportation or personal capabilities. In other cases, there is a need to remove people from locations and property impacted after an emergency has occurred.

It is not uncommon for families separated during the day to panic and try to take care of evacuation on their own. That can create traffic jams, confusion, and difficulty in locating family members they seek. Plans should address evacuations. For example, should there be an emergency situation at a school, a plan should identify how children will evacuate, and how they can connect with parents. Procedure may differ from normal use of buses or personal vehicles.

In some emergencies evacuation requires significant medical evacuation equipment, ambulances and supporting personnel. In some cases, such as flooding, boats and related water rescue equipment are necessary.

Sheltering One of the common needs during an emergency is housing and feeding people who have lost or cannot access their homes. An emergency plan should include establishing authorized sheltering locations. The sheltering organizations need to open when called and staff them as long as necessary. This may entail having a supply of food, water, toilet facilities, sleeping bags, medicine, resources, and other capabilities.

Public Safety and Other Resources Clearly, existing public safety organizations and personnel need to be ready to respond. These groups include police, emergency medical technicians (EMTs), ambulances, fire fighters, medical, and potentially military units.

In some emergencies, there is a need for utilities to shut off gas, water, and/or electrical service to prevent further harm or damage.

Step 3. Recovery Recovery is the process of assisting those impacted by an emergency to restore things to their previous state. It may include repairing and restoring infrastructure and buildings. It may be getting a business back into full operation. It may entail getting families back into their homes or replacement homes. It may require rebuilding roads and bridges, replanting trees and grass, removing debris and completing insurance claims, and other procedures. It can involve crisis counseling. There may be a need to organize volunteers and manage the damaged site.

Damage Assessment At first there is an effort to determine the overall amount of damage. That is necessary for a company or community to set recovery strategy or file for claims or assistance from government agencies.

There is also a need at an individual level to work with insurance adjusters on filing claims for losses experienced. It may also involve filing for assistance from government agencies. Depending on the scope of a disaster, the Federal Emergency Management Agency (FEMA) may establish offices in a community to assist in the assistance process.

Debris Removal The initial global assessment of damage may help define the need to implement contracts for

debris removal from excavators, demolition companies and trucking companies.

In some kinds of disasters, there is an overwhelming number of volunteers who wish to help. This requires rapid organization of cleanup and debris removal with an eye toward salvaging materials and personal items with financial and sentimental value.

The cleanup process may take weeks and months, depending on the kind and scope of a disaster.

Decontamination If an emergency involves hazardous materials, there may be a need to decontaminate people, equipment, and property. Responses addressing hazardous materials cases must remove continued threats to safety of employees, residents and others.

Restoring Essential Services Some emergency situations need to shut down power, fuel, water, sewer or other utilities. Emergency crews are often first on a scene to isolate dangers from their utilities and then to work at restoring them as quickly as possible. For example, cleanup activities may require electricity. Until utilities restore power, responders will need portable generators. A disaster may have produced broken water lines or damaged hydrants that need to be shut down. Fire fighters may need a supply of water to extinguish resulting fires.

Disaster Assistance State and federal governments or private relief agencies may declare an emergency situation some kinds of disaster. If there are disaster relief programs at any of these levels, an applicable agency must set up assistance centers. People will need help in working through the procedures that provide assistance through loans, grants, food supplies, temporary housing, or other means.

Crisis Counseling Some people will have a lot of difficulty dealing with an emergency situation. They lose focus on what needs to be done in any stage of the disaster. Some may have lost family, friends, co-workers or neighbors, or have to deal with their injuries. Some people can overcome the anxiety quickly and move ahead. Some have difficulty dealing with loss for some time. In many cases there is a need for a range of emotional, mental, and religious help.

Step 4. Prevention and Mitigation In some emergency management models there is another step focused on preventing a disaster, reducing its scope or reducing the potential for loss of life or property. Prevention addresses decreasing the likelihood that an emergency will occur. Mitigation action eliminate or reduce the loss of life and property for events that cannot be prevented.

Examples of mitigation mechanisms are building codes, zoning standards, or constructing levees. Others are qualifying a community for flood insurance.

Step 5. Evaluation and Update Some models include an additional step focused on a review of existing emergency management plans, especially after an emergency has occurred. The focus is on identifying lessons learned and finding ways to improve the existing plans. As noted earlier, emergency management is an ongoing process. Conditions change over time and plans need updating. Some planning models include activities related to this step as part of Step 1, Preparedness.

29-5 RESOURCES

There is a variety of resources available in planning and dealing with emergencies. This section will note a few.

Governmental bodies at federal, state, and local levels offer emergency management publications. At the federal level there is the Federal Emergency Management Agency (FEMA).[3] The Centers for Control and Prevention offers a comprehensive list of publications on emergency preparedness and management.[4]

There are private organizations that provide contracted services for planning and management of emergencies.

There are information resources on hazardous substances, such as the Chemical Transportation Emergency Center, CHEMTREC.[5] It offers a public service hotline for fire fighters, law enforcement, and other emergency responders, and for manufacturers and shippers to obtain information and assistance for emergency incidents involving chemicals and hazardous materials. Callers can obtain information on nearly three million material safety data sheets (MSDSs).

There are several industry and professional membership organizations that provide publications or other assistance for emergency planning. A few examples are the American Chemistry Council, Center for Chemical Process Safety of the American Institute of Chemical Engineers (AIChE).

29-6 SECURITY

Introduction

Often security and emergency management have similarities and overlapping roles. As noted in Table 29-2, terrorist threats can become a source of emergencies. The impact may be local, regional or national.

For many people responsible for safety, their job duties expanded after the events at the World Trade Center in New

TABLE 29-2 Examples of Terrorist Threats Important in Emergency Management

Explosions
Biological threats
Chemical threats
Nuclear explosions or releases from power plants
Radiological dispersion threats
Interruption of infrastructure (electrical grid, communications, computer systems, air travel, etc.)

York City on September 11, 2001. Duties included at least some responsibility for security related to protection of people and property. Safety specialists often work closely with security specialists and others on prevention of security incidents.

The approaches for managing security closely follow those for emergency planning and safety. The work begins with hazard (threat) recognition and continues to evaluation of their likelihood and severity (risk). It also involves establishing controls to eliminate or reduce the likelihood of damaging events.

Elements of Security

For most companies, security involves threats or risks to five kinds of assets. They are physical, information, financial, governance and human capital risks.

Physical Asset Risks Physical assets are buildings, production plants, warehouses filled with supplies or completed products, vehicles, machines and equipment, and other inventoried items. At risk are physical damage of various kinds, such as fire, structural damage, and even theft. Risks for physical assets can include interruption of the operations they house or support. An example for a manufacturer is the production plant and equipment, supplies and finished product. For an airline there are the planes, support facilities and equipment, and communication systems. For a retailer, there are supply vehicles, storage of goods in the distribution system, and the goods for sale in a store. The physical assets vary for each industry group.

Information Asset Risks Information assets are business, transaction and communication records. There are intellectual property rights, such as patents and inventions that give a company an advantage over other companies. There may be drawings, designs, plans, procedures, and calculations that support products and services. These assets may take physical and electronic forms. With the continual expansion of computer and Internet use, information assets pose greater and greater risks for all industries and organizations. With digital communications of all kinds through computers, tablets, and cell phones, there are many possibilities for intercepting and accessing current and previous voice, text and video communications. Simply losing a company laptop, tablet or phone with critical information may cause considerable harm.

Here are a few examples. The public is well aware of identity theft, often through hacks of retail and other company records and transactions. However, electrical grids are vulnerable as well and cyber attacks could shut down large segments of the electrical distribution system. The introduction of WiFi services on board commercial airliners poses the potential for a hacker to access the flight management computers. There are electronic threats to intellectual property and trade secrets of companies. Some countries have major, secret programs to capture classified information of government agencies in other countries.

Financial Asset Risks Financial assets involve the money, investments and financial transactions that support a business. It may include financial strategies and records of financial assets linked to banks, contractors, investment firms, and government agencies. Most financial assets are electronic. A few may be physical.

Governance Risks Governance of an organization involves compliance with laws and regulations and policies and procedures. It involves efforts to establish and maintain a culture that leads to the organization's success, profitability and value. The culture links the organization from the highest leadership level to the lowest level employee. Governance risk includes ethics, compliance with laws and regulations, loyalty, transparency, communication, and sharing of values.

Human Capital Risks Human capital is the collective skills, knowledge, or other intangible assets of individuals that create economic value for the individuals, their employers, or their community. Related attributes are habits, social skills, personality, creativity, leadership, etc. An organization loses human capital through job turnover, theft of intellectual property, non-commitment to group goals, and other means.

Approaches

The approach for managing security is much like other forms of emergency planning. The steps described for emergency management can apply to security. The steps are an ongoing, continual process to make improvements and strengthen security as new threats arise.

In Step 1, Preparedness. Security must begin by identifying the security threats for each type of asset. Then organizations develop plans and programs and position them to create barriers for those searching for vulnerabilities

and gaining access to any of the assets. It includes implementing monitoring for breaches of physical, electronic and procedural barriers. Step 1 involves training, education, system testing, audit reviews, and other ways of testing the effectiveness of security measures.

Step 2, Response. This involves having plans in place to react when an organization detects a breach of security measures. It may include participation by a variety of response groups, such as internal groups or external groups. Examples of the latter are police and government agencies in some cases. It may involve investigations to determine how security was breached.

Step 3, Recovery. This involves repairing damage to people, facilities, information, and business practices to restore regular business.

Step 4, Mitigation and Prevention. These require evaluations of current and breached security and developing improvements to prevent future breaches.

Layers of Security

For most security assets and risks, there are multiple strategies in place to achieve security.

Consider visitor access to a company facility. This example has a goal for protecting physical assets, information assets, human capital assets.

The first layer is perimeter security. Typically there is a fence surrounding a facility. The second layer is an entry point. Usually, this is a place to drive into a parking area after gaining approval from an entry guard. There may be a security desk at the building entrance. The entry point may include a third layer, detection equipment. There may be metal detectors. There may also be a requirement to show official identification and to leave a photo ID at the security station. A fourth layer may be interior security. The security desk may contact the persons to be visited to verify that they expect and know a visitor. Another internal security means is escorting all visitors to their destination. A fifth layer may be access control at the destination. That may be a keyed entry, use of an access control badge, or entering a code to open the entry door. The number of layers will depend on the amount of security deemed necessary.

Along the way, there may be security specialists who form a security team. For example, there may be a security officer who specializes in behavior detection. He works with other security specialists who are part of the team. The officer's goal is to identify individuals who act different from normal behavior and potentially pose a threat. Assume there may be an attacker. The officer can apply three security objectives: deterrence, detection, and prevention.

Deterrence is the ability to affect the motivation of an attacker and direct the person to a different target. Detection is the ability to identify the hazard as it develops. Prevention is physically intercepting the attacker.

The officer must learn what to look for and apply established protocols. The officer must learn to apply risk assessment, understand policies and protocols, work with others on the larger team, and evaluate performance.

Security can get rather complicated. Protection of different assets will involve a range of technologies to produce the number of security layers needed.

Resources

Security management has become a specialized field. One professional organization is ASIS International. Its members are security professionals. It offers many publications on a wide range of security topics. It produces standards for security.

ASIS International also operates a professional certification board. Those who meet qualifications and demonstrate knowledge in their specialty field can achieve one of the security related certifications.

Like other fields of practice, there are trade publications for security. They provide a means to stay current with security issues, equipment, methods, trends, conferences, and seminars.

29-7 A DISASTER DILEMMA

Technology solves some problems, but creates others. Trust in technology may lead to emergencies and disasters that may not have otherwise occurred. This is not something new. An engineer sold the town elders of Dixon, Illinois, a solution to their 600-ft river span. They paid him to build an iron bridge. On May 3, 1873, during the dedication of the new bridge, 200 people fell into the river and at least 38 died when the bridge collapsed. Cast iron did not have the strength properties necessary for a successful bridge. Cast iron, the metal of the time, is brittle, not ductile.

Some hailed the invention of the automobile as a solution to the traffic congestion and pollution of horse-drawn vehicles. At the turn of the century in New York City horses deposited 2 ½ million pounds of manure and 60,000 gallons of urine per day on the streets. The automobile created pollution problems and gridlock. More than 30,000 people die each year in the United States from automobile accidents.

During the twentieth century the United States spent billions of dollars to control the erratic behavior of waterways. It appeared that levees could control rivers and coastal areas. However, hurricanes and abnormal water loads still produce wide destruction. Some of the damage results from

people building on reclaimed land with an expectation that the area is safe. The levees in New Orleans could not contain the water levels produced by Hurricane Katrina in 2005. The levees were not high enough.

The 1984 chemical plant tragedies in Mexico City and Bhopal, India, would probably have been much less destructive had there been restrictions on dense populations living adjacent to the plants. Both locations had squatters' shacks in proximity of the industrial complexes.

The past events should not dampen the use of technology to solve the problems of the human race. Perhaps with greater foresight and a wider view of potential consequences, we would see fewer emergencies and disasters. Planning for emergencies should also lead to preventive actions so that emergencies are less likely to occur.

EXERCISES

1. Locate the local public emergency response organization. Find out how it is organized and operated. Identify its members and participating organizations. Determine what kinds of emergencies it has plans for.
2. Obtain a copy of an emergency response plan from a company. Evaluate its contents.
3. Select a natural and a human-made emergency where you live. Draft an emergency plan for each.
4. Select an emergency or disaster, such as a hurricane that struck the Northeast corridor of the Atlantic Ocean or a Gulf of Mexico city. Identify what damage may have resulted because people relied on technology. Determine if local, state, or national regulations were modified after the disaster to prevent similar damage in the future.

REVIEW QUESTIONS

1. What is an emergency?
2. What is a disaster?
3. Where and to whom can emergencies happen?
4. Name five kinds of natural emergencies and give an example of each.
5. Name four kinds of man made disasters.
6. Identify three kinds of terrorist emergencies.
7. List the four priorities of an emergency in order from highest to lowest importance.
8. Identify and describe the key steps in emergency management.
9. Identify and define the five kinds of assets important for security.
10. Give an example of multiple layers of security for:
    - **(a)** physical assets
    - **(b)** information assets
    - **(c)** human capital assets

NOTES

1 www.epa.gov/oswer/riskassessment/risk_ceppo.htm

2 www.fema.gov/plan-prepare-mitigate

3 *Are You Ready? An In-depth Guide to Citizen Preparedness*, August 2004. www.fema.gov/media-library/assets/documents/7877

4 www.cdc.gov/niosh/topics/emres/business.html

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CHAPTER 30

FACILITY PLANNING AND DESIGN

The best time to incorporate safety into a facility is during the requirements, planning and design phases of a new facility or the modernization of an existing facility. Figure 30-1 illustrates the increased cost to make a change in a project the further into the process a change occurs. The lowest cost occurs in the early stage when organizations define their requirements. The highest cost occurs after completing construction and occupying the facility.

For some designers, safety is an afterthought. Some designers do not find safety important until after construction has started or a facility is complete. Incorporating safety during design makes economic sense because it is much cheaper to make changes early during design. It is more expensive to negotiate change orders with a contractor or to modify a facility after completion.

30-1 FACILITY DEVELOPMENT PROCESS AND SAFETY

Figure 30-2 represents one way to describe the facility procurement process. Because conditions and requirements change, the process of keeping facilities supportive of an organization and its operations is cyclical and continual. Organizations obtain facilities through new construction, leasing, and modification of existing facilities.

A facility design must consider safety, health, and environmental factors throughout the process. Safety considerations do not occur during just one step. Safety factors cannot wait until the completion of a project.

Recognizing the Need

Typically, the facility development process begins with recognizing the inadequacies of an existing facility. A facility project may begin when an organization expands and current facilities cannot accommodate expansion.

The need for a new or upgraded facility may result from inadequate safety features. Risk analysis for business change (see Chapter 34) may uncover the likelihood or consequences of a potential loss. The cost of a potential loss may help justify a facility project. Changes in safety and environmental regulations and standards may require facility modifications.

Planning and Budgeting

Once an organization determines a facility need, preliminary planning and budgeting begin. Some call this a feasibility study. In preliminary planning, a design team estimates the scope of the project and creates a general concept for it. The team may develop and evaluate alternative concepts.

Defining Requirements The design team will need to compile requirements of various types. Requirements define the size of the project. They also identify the equipment and furnishing the facility will house, the number of occupants or workers, and the number of shifts They state the need for building systems. Building systems provide heating, cooling, communications, lighting, emergency lighting, fire protection, noise control, ventilation, water, sewer, electrical systems, sensors, alarms, radiant shielding, and waste management. Some activities may require physical separation or shielding.

Safety specialists, often working with others, need to define what safety features and support systems provide the level of protection necessary for occupants and operations.

The planning process should also include risk analysis. Identifying what can go wrong including the probability of occurrence and the severity of consequences will help with requirements. Requirements to support normal operations may differ from emergency events.

Defining the safety features and support system requirements for safe occupancy helps in design planning. Designers can assure that layouts and cost analysis will support safety as well as occupants and their operations.

Preliminary Cost Estimates Once a design team develops preliminary options, specialists can make cost estimates for completing the project. The cost will help determine which option is best.

Participants in the preliminary planning may critique the options and offer feedback about why one option is better

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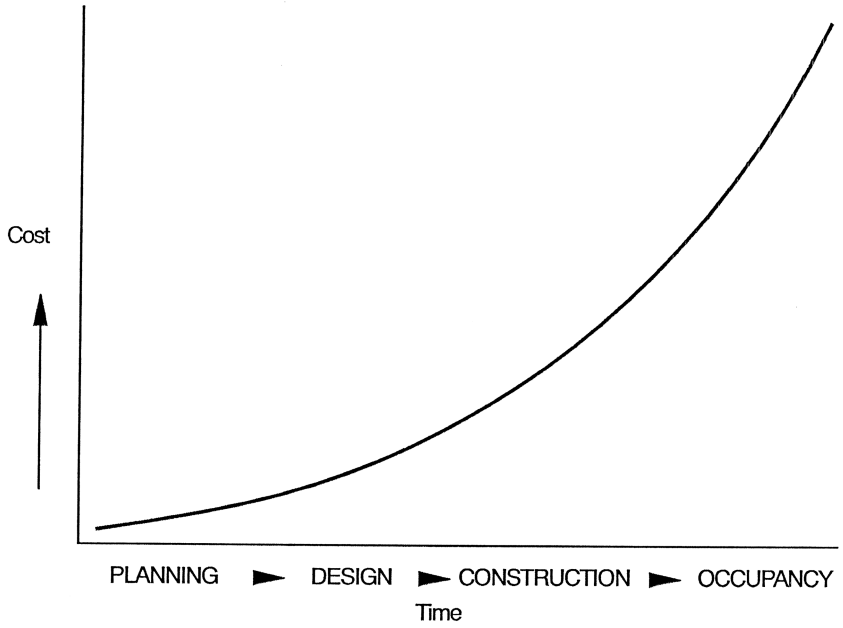


Figure 30-1. Building development and cost of change by project phase.

than others. Decision-makers will determine whether the organization has funds sufficient to move the project ahead.

Predesign

Once an organization selects a course of action, the next task is to work on details. One of the tasks is verifying and gaining more information about requirements. The design team will work out layout details, craft specifications for building systems, and begin selecting materials.

For example, from a safety perspective someone needs to compute the water supply requirements for fire protection and other uses. Someone needs to identify which spaces or operations need emergency lighting or power. A safety specialist may need to conduct a preliminary hazard analysis or other analysis for some or all operations or spaces. The results will give the design team information to incorporate into the design.

Once again the design team will verify cost estimates based on the updated information. Decision-makers will determine if the project moves forward.

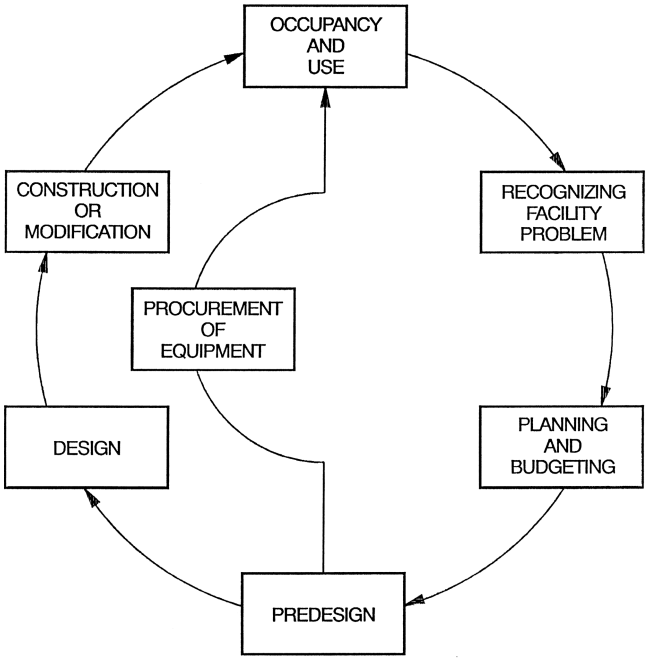


Figure 30-2. The facility procurement process.

Design

With final project approval, the design team will develop a final design for the project. The final design will try to meet as many requirements as possible. It may not be possible to meet all requirements. Designers may seek trade-offs to meet cost constraints or building systems requirements. Safety specialists must state which safety requirements are not negotiable. They may need to discuss options with designers and possibly find ways to meet requirements in other ways than initially proposed. Designers may need help in identifying what standards and regulations apply.

Part of a final design is the supporting documentation on materials and building systems. Safety specialists may need to help designers with that task. For example, the building may include various warning and safety signs. It may include safety systems intended for emergency use. There may be a need to perform preventive maintenance on these features. The

procedures for safely operating and maintaining these features must be part of the documentation delivered with the facility. A facility design should consider how easy or difficult maintenance tasks are. Even simple tasks like changing a light bulb may require special equipment to reach the bulb and may create hazards for maintenance workers.

Selection and Procurement of Equipment

In some cases, the safety systems needed may be part of the procurement process and not part of the facility itself. Safety specialists will need to identify safety requirements that must be part of building systems and those that apply to purchased equipment.

The procurement process for equipment and furnishings for a facility moves parallel to the building design and construction process. At some point the two processes merge to finish a project. The procurement process begins with requirements, plans, and cost analysis. It progresses toward ordering, assembly, and testing concurrent with the facility itself. Very often an engineering team handles the design, selection, and implementation of the process systems.

A safety specialist will need complete analysis of the equipment and processes and define hazards of and safety requirements for purchased items. Risk analysis will also apply to help envision safety concerns, features, controls, and practices.

In some cases, such as chemical process facilities, the equipment is an integral part of the facility and the two aspects occur together.

When purchasing equipment, safety specialists must specify required safety features. In some cases, a company may have a fabrication company build custom equipment. The fabricators must know what safety features are part of the procurement.

Purchasing agents should not have to decide about hazards and controls when buying equipment. Specifying safety requirements requires a team effort between safety specialists and others. The team must also determine compliance with requirements The team will decide whether workers can operate equipment safely.

Construction or Modification

After completing a design, a facility project moves to construction. The project may be new construction or modification of an existing facility. Contractors will do the construction work. Contractors also install new or modified equipment.

Part of construction or modification is quality assurance. Designers implement steps to assure that contractors build a facility that meets the design specifications. This may require testing, evaluation and formal acceptance procedures. The designer must be sure that contractors do not make changes that introduce dangers. They must verify that contractors construct and install safeguards correctly.

During acceptance, owners must verify that building layouts and systems meet requirements defined early in the project. This may require a safety specialist to conduct a review to establish if safety requirements are in place.

Occupancy and Use

After completing a facility project, occupants move in. They put the facility to use. It should meet its functions safely. It is not unusual after moving in to find the need for some adjustments. Those may include safety features. Users may change operations and activities that reduce the effectiveness of some safety features or requiring new ones. There must be continual monitoring of hazards and controls for them after moving in.

30-2 TOOLS TO HELP SAFETY IN DESIGN

There is a variety of tools, concepts, and procedures that help designers reach solutions that satisfy as many requirements as possible. This book includes some tools. Examples are use of the Energy Theory (see Chapter 3) and the Four Ms and Goal Accomplishments Models (see Chapter 9). They help with hazard recognition. Other kinds of tools can also help.

Later chapters (Chapters 34–38) describe risk analysis and other procedures and methods for identifying hazards and selecting and ranking controls. These procedures help apply knowledge about hazards and controls covered in other portions of this book.

There are many references that deal with the control of hazards in facilities. There are laws, regulations, and consensus standards for many kinds of hazards. There are references containing design guidance and criteria that capture the experience of others. Some of these references deal with particular kinds of facilities.

Table 30-1 is a checklist derived from a survey of process company experiences. The survey compiled data on what went wrong with process facilities. Many of the entries in the list apply to other types of facilities.

Organizations such as Underwriters Laboratory[1] and FM Global (formerly Factory Mutual System)[2] offer publications and services that draw on years of experience with hazards in facility designs.

Another important factor for incorporating safety in facility design involves the makeup of the design team. Safety and health specialists should be a part of the design team or an advisory panel for the design team. There is an increase in the use of safety specialists as part of facility planning and design. The safety specialist should have broad knowledge in safety, health, environmental, and fire protection subjects.

For example, many petroleum and chemical companies have safety engineering specialists involved in the planning and design of processing plants and facilities. The Department of

TABLE 30-1 Checklist of Hazard Factors for Facility Design and Operation[a]

1. Plant Site Problems
Unusual exposure to natural emergencies
Inadequate water supply and other utilities
Exposure to hazards from nearby plants
Unreliability of public fire and emergency protection
Traffic difficulties limit emergency equipment access
Air and water pollution problems
Inadequate waste disposal facilities
Climate problems requiring moving hazardous processes indoors
Poor drainage

2. Inadequate Plant Layout and Spacing
Congested process and storage areas
Lack of isolation for very hazardous operations
Exposure of high value and difficult-to-replace equipment
Lack of adequate emergency exit facilities
Insufficient space for maintenance or emergency operations
Source of ignition too close to hazardous materials
Critical plant areas exposed to hazards
Inadequate hazard classification of plant areas
Lack of isolation of critical plant areas from community

3. Structure Not in Conformity with Use Requirements
Disregard for code requirements
Lack of fire-resistive structural support
Failure to provide blast walls or cubicals to isolate extra hazard operations
Inadequate explosion venting and ventilation of buildings
Insufficient exit facilities
Electrical equipment doesn't meet code
Unprotected critical wiring
Inadequate hazard anticipation (i.e., explosion)

4. Inadequate Material Evaluation
Fire, health and stability of materials not evaluated
Inadequate controls for quantities of materials
Inadequate evaluation of processing environment for hazards of materials
Lack of information on dust explosion properties of materials
Inadequate evaluation of health hazards of materials
Incomplete inventory of hazardous materials in the plant
Lack of long term exposure information
Improper packaging and labeling of chemicals

5. Chemical Process Problems
Lack of information on process temperature and pressure variations
Hazardous by-products or side reactions
Inadequate evaluation of process reactions
Lack of identification of processes subject to explosive reactions
Inadequate evaluation of environments
Overlooking conditions for extreme process conditions
Lack of evaluation of vapor cloud hazard

6. Material Movement Problems
Inadequate control of chemicals during night operations
Inadequate control for hazardous dusts
Piping problems
Improper identification of hazardous material during transportation
Loading and unloading problems
Inadequate control of heat transfer
Flammable gases and vapor problems in pneumatic conveyors
Waste disposal and air pollution problems
Vapor cloud problems

7. Operational Failures
Lack of detailed descriptions and procedures for operating all sections of the plant
Poor training program
Lack of training on health hazards
Lack of supervision
Inadequate start-up and shutdown procedures
Poor inspection and housekeeping
Inadequate permit system
Lack of emergency control plans
Inadequate drills
Lack of medical and biological surveillance

8. Equipment Failures
Hazards built into equipment
Corrosion or erosion failures
Metal fatigue
Defective fabrication
Inadequate controls
Process exceeded design limitation
Poor maintenance program
Inadequate repair and replacement program
Lack of "fail-safe" instrumentation
Poor check on construction criteria or material specification
Equipment not capable of toxic or hazardous materials

9. Ineffective Loss Prevention Program
Inadequate support by top management
Lack of assigned responsibility
Poor accident and hazard prevention program
Insufficient fire protection manpower, equipment and organization
Ineffective explosion prevention and control program
Lack of emergency planning
Poor check on boiler and machinery risks
Lack of preemployment physical examinations and periodic checkups
Lack of training on health hazards and use of personal protective equipment
Lack of conformance with government regulations
Insufficient in-plant monitoring of physical and chemical hazards
Individual hazard approach instead of "total loss control" concept

[a]Derived from *Hazard Survey of the Chemical and Allied Industries*, American Insurance Association, New York, 1979. The items resulted from a questionnaire survey of failures of many plants and operations.

Defense requires that projects use system safety (Chapter 36) for major facility projects. The Corps of Engineers has publications covering various aspects of facility planning and design.[3]

If safety specialists are not part of a design team, at least there should be a thorough safety review of a design by a safety specialist. The review should cover safety features built into the facility and safety during use of the facility. The review should consider operation, maintenance, repair, and servicing of the facility and its subsystems and equipment. The design must cover routine use of a facility and activities of facility caretakers. It must cover special activities important for emergencies and rescue.

One way to approach design review is to consider individual elements of a project. One can use scale to organize the project components. At the largest scale is the *site* and *siting*. Next is evaluation of the *building* or *facility*. The process proceeds to the facility *interior* and *occupancy*. In some cases evaluation proceeds to specific *work stations*. All throughout the process, reviewers must consider *equipment*, *operations, processes*, and *activities* at each level. Reviewers must assure compliance with controls for hazards for each element. Table 30-2 provides a checklist covering some considerations when dealing with a building or facility project.

TABLE 30-2 Incomplete List of Safety Considerations in Facility Planning

SITE	
Drainage	Prevention of spills, leaks, or activities that may contaminate storm water or limit runoff control.
	Flood control and protection.
Utilities	Prevention of damage to utilities (power lines, pipelines, communication lines)
	Remote shutoff of utilities.
	Barricades to protect people from utilities.
	Water supply for operations and fire protection.
	Storage of fuels on site.
Traffic	Traffic load on or adjacent to site (pedestrian, vehicular, railroad, public, employees, delivery, etc.)
	Need to separate kinds of traffic.
	Types and quantities of materials entering or stored on site.
	Access for emergency vehicles and equipment.
Hostile Conditions	Wind loads and conditions.
	Snow loads.
	Earthquake zones.
	Lightning protection.
	Protection from sun, water, weather, or other hazards.
	Physical security.
Site Storage	Storage of fuels, water, hazardous materials on site (type and quantity).
	Separation requirements.
Adjacent Properties and Community	Barricades and fences to keep unauthorized people from dangerous areas or materials.
	Protection from hazards of adjacent or nearby properties or transportation routes.
	Dangers to adjacent properties from site or operations.
	Emergency response plan.
	Community right-to-know requirements.
	Emissions and controls.
Fire and Emergency	Access for emergency vehicles and equipment.
	Fire load.
	Fire response management.
	Fire suppression and extinguishment.
BUILDINGS	
Walkways, Stairs and Access	Adequate lighting at entries, transition points, stairs, landings, etc.
	Guard rails for elevated surfaces.
	Hand rails for stairs and certain types of pedestrians.
	Hand rail dimensions for firm grip.
	Floor finishes to minimize slipperiness, prevent corrosion, etc.
	Drainage or raised flooring for wet or oily areas or where foreign material is slippery.
	Spill isolation to prevent distribution of contaminants.
	Minimize changes in surfaces (elevations, irregularities, slipperiness).
	Aisle and area markings for pedestrian areas, vehicles, materials, handling, or hazardous operations.
	Door sizes for vehicles and materials.
	Safe access for building and equipment maintenance.

Hazard Zones	Enclosure, isolation, separation, or other controls for hazardous sources (noise, gaseous or particulate contaminants, etc.)
	Exhaust ventilation, hoods, or cabinets for hazardous contaminants.
	Barricades for hazardous operations.
	Sensors and monitoring equipment for hazardous materials.
	Warning signs that meet various standards and markings to identify hazardous areas.
	Communication systems.
Fire Protection	Fire loads.
	Smoke and heat detectors.
	Alarm systems and evacuation management systems.
	Sprinklers and other fire suppression equipment.
	Fire ratings for materials, finishes, and partitions (walls, ceilings, floors, doors).
	Exit signage.
	Roof vents and curtain boards.
	Explosion venting.
	Fire control equipment and systems for flammable operations.
	Utility shut off systems for emergencies.
Sanitation	Sufficient washrooms.
and First Aid	Clean areas for food and eating, including isolation from sources of contamination.
	Lockers, change rooms, and showers for control of contaminants.
	Emergency showers.
	Emergency eye wash fountains.
General	Enclosure of dangerous equipment and building systems.
	Maintainability to minimize repair, cleaning, and servicing hazards.
	Storage areas for hazardous materials.
	Proper separation of noncompatible materials.
	System, equipment, and operations shutoffs in nonhazardous areas.

30-3 SITE CONSIDERATIONS

There are many safety consideration in a facility design. This section discusses some elements of the overall site.

Location

There are many location factors that impact plant design and potential hazards.

Climate and Natural Conditions In planning a facility, there is a need to know about wind, particularly if there are any potential releases from the facility. Drainage is important. There should not be an accumulation of water from processes, leaks, or storms. Hazardous materials should not contaminate runoff water or affect site neighbors. Stored materials should not create pollution. Designers must know if there is a flood potential. They must know if there are dangers from flight paths, nearby rail lines, highways, and other forms of transportation. Soil characteristics, such as water table and ground water, are important in case of spills.

Neighborhood and Population There is a need to know about the population living or working in the vicinity. For example, do people live very close by? Is the facility adjacent to schools or parks? Are there other plants or operations nearby that have dangers? Designers need to know if there are periods with high densities of people from traffic or special activities. Other considerations are knowing if there are playgrounds or schools nearby or if nearby plants and operations create hazards.

Size of Site

If there are hazards such as noise, explosions or heat, the distance to the periphery of the site and between parts of the plant or facility must be great enough for protection.

Access and Circulation

The site should have adequate access for facility occupants, emergency equipment, and delivery vehicles. If possible, circulation routes for pedestrian traffic should not have to cross vehicular traffic routes. Both normal and peak traffic should not block emergency access. Materials handling, delivery and rail traffic should have isolation from employee and visitor parking and walkways.

Layout

The site arrangement should isolate hazardous materials and operations from non-hazardous activities. As few people as possible should have exposure to any hazard. Quantities of materials, particularly those with high energy content, should

be separate from activities that could trigger fires or explosions.

Utilities

Utilities locations should avoid creating hazards. For example, gas lines should not be near rail lines or public or employee areas. Shutoff locations should avoid locations where the utilities might create hazards. Shutoff controls should be accessible to emergency crews even during incidents. Power and other utility lines should have protection from vehicle damage. Utilities, such as water, should be sufficient for emergency needs. Supply mains must effectively service use points in the facility.

There should be consideration of effects of power outages. Examples are shutdown of ventilation systems, loss of primary lighting, and interruption of processes and computers. There may be a need for uninterrupted power supply (UPS), alternate power, or generator sets and battery systems.

Storage

There should be sufficient storage capacity for anticipated and excess quantities of materials. Hazardous materials should have isolation from other materials and have specific areas on the site. Storage equipment and layouts should minimize traffic problems for materials handling equipment.

Security

The facility project must consider the need for security of the site and elements on it. For example, the facility may have control points for anyone entering the site and for access to plant areas or administrative areas. There may be a need for additional security for hazardous areas. Hazardous areas may require fencing, monitoring cameras, and other physical security equipment to monitor unauthorized access.

30-4 BUILDINGS AND FACILITIES

Specific building types will present hazards and conditions that are unique to that building type. Below are some general considerations.

Layout

Designers should separate processes that have noise, heat or cold, require ventilation or have other environmental hazards from areas that do not have these hazards. That reduces the need for protective features and materials. There may be a need for partitions to isolate fire hazards.

Access and Circulation

Review whether emergency equipment and personnel have easy access to all locations. Arrange circulation to prevent traffic congestion and conflicts between vehicular and pedestrian traffic. There should be enough exit routes and exit units to meet life safety standards. Doors should also have enough width and height for vehicles and materials handling equipment. Circulation areas should have visible marking.

Materials of Construction

Designers need to select materials to meet fire protection requirements, withstand corrosion, or not lose strength from reactive materials that will occur in the building. They may need materials to control noise or reflect light to aid vision.

Flooring

Flooring selection involves many factors. Floors must carry the anticipated loads. When modifying a facility, structural analysis will determine if anticipated loads are possible. In general, surfaces should be slip resistant. Floor surfaces should avoid sudden changes in slipperiness coefficients. Surfaces should avoid small changes in elevation (one or two steps) and minor height changes that create tripping hazards. There is a need for protection of open stairs and other openings. Avoid patterned finishes on stairs that make it difficult to see elevation changes. Avoid sudden changes in the view from stairs that create visual distractions and cause falls.

Ventilation

Check operations for generation of heat, gases, vapors, or airborne contaminants. Place them in locations to minimize the portions of the building affected. Capture contaminants at the source to minimize the volume of air requiring treatment. Consider the effects of spills and leaks and how to manage them.

Lighting

Besides adequate lighting for routine activities, watch for transition zones near entries. Make sure these zones allow for eyes to adjust, particularly if a transition from bright sunlight leads to stairs or other walking hazards. Determine if interior spaces have adequate emergency lighting to allow for safe exiting.

Storage

Analyze the types and quantities of materials that will be present. Plan storage locations for each type of item. Separate incompatible materials, such as oxidizers and fuels. Provide adequate storage equipment and racks to keep materials organized. Clearly mark storage areas for particular items.

Communication

Consider routine and emergency communications. If there are potential emergencies, provide communication systems that can reach occupants to inform them of dangers and the corrective actions to take. Voice systems may need equipment dedicated for emergencies to assure that emergency communications do not compete with regular communications. There may be a need for video systems for security. There may be a need for computer and recorder systems for monitoring equipment for safe operations.

Fire Protection

Analyze the fire loads and fire controls. Determine if compartmentation is adequate. Analyze water supplies for adequacy at all locations where there is a need for extinguishing water or emergency showers. Consider the value of sprinkler systems and the type best suited to each location.

Maintainability

A building design factor that impacts safety of maintenance people is designing building systems and components that allow for easy and safe maintenance. For example, utility spaces that are very tight limit the ability to remove components for service and repair. Heating and air conditioning components that have no access walkways create dangerous service work. Placing control valves behind equipment make them difficult to find and access. Lighting fixtures that require special equipment to change bulbs may encourage unsafe work setups. Plumbing and electrical systems without proper shutoff valves and controls may lead to dangerous repair and service work. Unprotected skylights on roofs can become work surfaces during repair and maintenance. Skylights do not support people standing on them.

30-5 WORK STATION CONSIDERATIONS

Work station design must address hazards of particular tasks. There should be room to sit and stand. Seating should be comfortable and adjustable. Minimize materials lifting and handling. Furniture and layouts should avoid the need to twist, turn, bend or stoop. Review the ergonomics aspects of work station and equipment designs (Chapter 33).

30-6 EQUIPMENT AND PROCESS CONSIDERATIONS

There are many safety considerations for equipment. Proper controls, guarding, noise characteristics, electrical grounding and other factors are important. One must apply techniques to identify hazards, risk (Chapter 34) and options for eliminating or reducing risks. Facility designers should specify safety features for furnishings. Do not leave decisions about safety requirements to procurement people.

For process equipment, designers need to specify necessary safety features and the tests for meeting requirements. For process equipment, there should be fail-safe features. Fire protection, overpressure, excess heat, runaway reactions, dust control, exhaust ventilation, dangers of flammable liquids, leaks, sensing devices to report status are all examples of important safety features. Designers and purchasers need to consider access for setup, maintenance and cleaning. There may be a need for access by stairs, fixed ladders or platforms as part of large equipment.

Chapter 24 addressed compliance with the OSHA Process Safety Standard[4]. Many references from the Center for Chemical Process Safety[5] provide details for identifying and controlling hazards in process plants.

EXERCISES

1. Obtain the drawings and specifications for a public assembly, commercial or retail building. If documents are not available, visit an existing building. Evaluate the design for safety of employees and public users and their activities. Prepare a report of findings indicating to the designer what is wrong or can be improved for safety and what corrections you recommend.
2. Meet with designers from an architect-engineering firm. Ask them how they incorporate safety into their facility planning and design process.
3. Review a process safety audit report. Summarize the procedures used and the resulting recommendations. Find out how the results were actually implemented.

REVIEW QUESTIONS

1. When is the best time to identify safety requirements for a facility?
2. Describe major steps in the facility development process and safety considerations for each.
3. Who is the best person to identify safety features when procuring equipment?
4. What are some resources for information about safety in facility design?
5. Identify three safety considerations for each of the following:
   (a) site
   (b) building

(c) work station

(d) equipment

NOTES

1 Northbrook, IL www.ul.com

2 Norwood, MA www.fmglobal.com

3 www.publications.usace.army.mil/

4 29 CFR 1910.119, *Process Safety Management of Highly Hazardous Chemicals*. www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760

5 www.aiche.org/ccps

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PART IV

THE HUMAN ELEMENT

THIS SECTION of the book discusses elements of safety that involve the individuals who are the main targets of hazard recognition and control.

There are two main causes of accidents: unsafe conditions and unsafe acts. Engineers deal mainly with unsafe conditions. The major role of engineers is prevention through hazard recognition and controls in the design of equipment, environments, vehicles, and facilities.

Many involved in safety consider preventing unsafe acts as a people problem. They must gain the cooperation and participation of workers and managers to achieve safe conditions and operations.

Rarely, however, is either an unsafe act or an unsafe condition the single cause of an accident. Most cases have elements of both. This section considers the role of individuals. Part V addresses the role of management and organizations.

To prevent accidents by preventing unsafe acts, one must prevent behaviors that lead to accidents or mitigate the effects of unsafe acts in a sequence that leads to an accident. To deal with unsafe acts and their roles in accidents requires an understanding of human behavior and the factors that influence behavior.

Many engineers learn little about preventing unsafe behaviors through design. Many designs or design features can eliminate the potential for unsafe behaviors. Designers need to understand human behavior, human capabilities, and human limitations. By making designs fit people, rather than changing people to fit designs, engineers can reduce the role of unsafe acts in accident processes. Chapter 33 discusses ergonomics as an important part of design.

Earlier discussions of the priorities for hazard controls noted that the last priority involves procedures, including the use of personal protective equipment. Effective designs for safety minimize the need for simple or complex procedures that require extensive training and skills. Legal issues discussed earlier identified the need to provide warnings and instructions to prevent injuries. Failure to warn about hazards in products and processes creates a liability for a designer and/or manufacturer.

This section also looks at training that helps people follow safe procedures. There are methods for identifying which behaviors are correct and safe for various jobs. There are many laws, regulations, and standards that require employers to train workers in safe practices. Managing safety training is a major job role for safety specialists.

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CHAPTER 31

HUMAN BEHAVIOR AND PERFORMANCE IN SAFETY

Workers and others are the most important focus of accident prevention. Along with property and the environment, people are the objects of efforts to achieve safety and health in workplaces, in products and in public places.

Chapter 3 introduced unsafe acts as one of the factors leading to accidents. Unsafe acts are human behaviors. Those pursuing accident prevention apply much effort on ensuring safe behavior along with hazard recognition, evaluation and control.

There are many accident cases that raise questions about individual behaviors and whether the individuals caused, contributed to or were simply victims of malfunctions. Investigations can help uncover the role of unsafe conditions and the acts of individuals involved.

Consider some cases that illustrate the issues of accidents and whether human behavior was a factor. They illustrate the complexities often involved.

CASE 31-1

The local newspaper reported a head-on vehicle crash that went virtually unnoticed. Robert W., the driver of an automobile, suddenly swerved into the path of an oncoming semitrailer rig. The accident demolished the automobile. Robert W. was pronounced dead at the scene. The truck driver received facial injuries and two broken ribs.

Why did the accident happen? Did Robert W. suddenly get ill and lose control? Was there an icy patch on the pavement? Both were possibilities. However, only family and close friends had another theory for the accident: Robert W. had terminal cancer and recently was depressed. He may have committed suicide.

CASE 31-2

The accident report seemed simple enough. Gary did not see the step, fell and broke his arm. Gary came to work that morning, entered the building and started down the hall to his office. About 10 ft from the door, there was a step down into the new part of the building. Somehow he missed the step and fell forward. He put out his hand to stop the fall and broke his arm. That seemed straightforward. He made a dumb mistake; he was not paying attention.

You see, the day started terribly. Gary had not been getting along well with his wife. They were getting close to divorce proceedings. The night before they had had another argument. In the morning, one of the children was sick and could not go to school. Gary had to find a baby sitter. A neighbor who usually helped out was gone for a couple of days. So Gary called his sister, who agreed to help out. However, she lived 30 minutes away. He rushed the child to his sister's and then drove to work.

That morning there was an important meeting and Gary had to deliver a report on the performance of his production team. Already late, Gary arrived to find a delivery truck blocking his parking place, which forced him to park way in the back part of the lot.

As he ran from his car, the morning sun was virtually in line with the door of the building. He had trouble looking up as he approached the building and the sun glared into his eyes. Once inside the entrance from the parking lot, it was somewhat dark. Gary had a lot on his mind thinking about the report, the sick child, and his strained relationship. Then he fell.

What was the cause of Gary's accident?

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CASE 31-3

Maria B. operated a molding machine that turned out plastic parts. The machine normally operated in automatic mode. Dies came together horizontally. The machine injected molten plastic between the dies. When the dies opened, the formed part fell to a parts box below. Somehow, Maria put her hand between the dies, the dies closed and crushed her hand.

Why did the accident happen? Did someone accidentally trip the machine? Why did Maria put her hand in the machine anyway? Why was the guard not in place? Would it have prevented the accident? The accident seemed unnecessary. It appeared that Maria had made a stupid mistake. Did she not read the warning sign that said; "Never reach into the machine while it is on."

Maria was new on the job. In fact, it was her first day. Her boss had taught her how to do the job just that morning. She had been on her own for only 45 minutess. Maria did not speak English very well and could not read English. She was thrilled to have the job so she could help out her poor family. Compared to previous work, this job paid well and she wanted to do a good job for her new boss. She did not want to make a mistake.

The guard was removed the day before to set up a new process. The interlock was wired down to allow for testing by the tooling department during the morning shift. The idea was to make sure the machine operated correctly during the night shift using manual mode. Then the goal the next day was having the maintenance crew (who only worked days) replace the guard, reactivate the interlock, and return it to automatic mode.

When the machine started to malfunction, the dies opened but the part did not fall like it should have. Maria had learned nothing about that. She was trying to do her best. She was afraid her boss would be angry about bad parts. He was anxious when he showed her how to run the machine and was obviously under stress about the startup. As she reached into the machine to get the part loose, she accidentally bumped the foot control that tripped the machine.

To compound all the other factors, the machine had the wrong control. The machine design intended automatic mode. Manual operations for this machine required a hand control for protection. However, the previous owners had set it up differently for automatic mode only. The hand controls were no longer on the machine. Maria's company was having trouble meeting production demands, had a large order to fill, and had just added a night shift. They got the used machine at a bargain price. The company had its tooling department refurbish it and rush it into operation.

What caused this accident?

31-1 HUMAN BEHAVIOR

Why do people behave as they do? What makes them tick? Some people never seem to have a problem. Others seem to be accidents waiting to happen. Some get along with everyone. Others are impossible to deal with. Some days we feel good and enjoy family, work, and life. Some days we do not feel good and become irritable to everyone.

Human behavior is very complex. It is not fully predictable. Often, behaviors contribute to accidents. Many factors affect behavior (see Table 31-1). Examples are physiological condition, biochemistry, health, relationships with others, personal desires, and career goals. This chapter looks at human behavior and important characteristics of it.

Theories of Behavior

There are many theories of behavior. Some are descriptive theories. They offer characterization or classification of a person after observing that person's behavior. Some theories are predictive. They attempt to predict what a person will do given information about their past, their surroundings or individual attributes. Behaviorists obtain the information by introspection or subjective or objective means.

Early theorists believed that behavior had biological origins. Theories related observable behavior to instincts, habits, and conditioned reflexes from repeated stimuli. Later, other theorists looked to underlying elements within an individual that were not accessible through introspection by the individual. Others looked to many factors that together cause behavior. Examples include inherited traits and characteristics and environmental factors that lead to a person's behavior. The inherited traits may be both physiological and psychological. The environmental factors may be an accumulation of experiences in particular situations or conditions surrounding one at any moment.

Heinrich relied on some of these theories to form his Domino Theory of accident causation. See Chapter 3. Today, other methods describe how leaders impact work-related behavior and accident prevention.

Motivation

Motivation is that part of psychology that deals with getting someone to perform desired behaviors or actions. Motivation involves content and process theories. Content looks at the characteristics of an individual or the environment that

TABLE 31-1 Performance Shaping Factors[a]

Situational Characteristics	*Psychological Stresses*
Temperature, humidity, air quality	Task speed
Noise and vibration	Task load
Degree of general cleanliness	High jeopardy risk
Manning parameters	Threats (of failure, loss of job)
Work hours/work breaks	Monotonous, degrading, or meaningless work
Availability/adequacy of supplies	Long, uneventful vigilance periods
Actions by supervisors	Conflicts of motives about job performance
Actions by co-workers and peers	Reinforcement absent or negative
Actions by union representatives	Sensory deprivation
Rewards, recognition, benefits	Distractions (noise, glare, movement, flicker, color)
Organization structure (e.g., authority, responsibility, communication channels)	Inconsistent cuing
Task and Equipment Characteristics	*Physiological Stresses*
Perceptual requirements	Fatigue
Anticipatory requirements	Pain or discomfort
Motor requirements (speed, strength, precision)	Hunger or thirst
Interpretation and decision making	Temperature extremes
Complexity (information load)	G-force extremes
Long- and short-term memory	Atmospheric pressure extremes
Frequency and repetitiveness	Oxygen deficiency
Continuity (discrete versus continuous)	Vibration
Feedback (knowledge of results)	Movement constriction
Task criticality	Lack of physical exercise
Narrowness of task	*Individual Factors*
Team structure	Previous training and experience
Human-machine interface factors (design of equipment, job aids, tools, fixtures)	State of current practice or skill
Job Instructions	Personality and intelligence variables
Procedures required	Motivation and attitudes
Verbal or written communications	Knowledge of required performance standards
Cautions and warnings	Physical condition
Work methods	Influence of family and other persons or groups
Shop practices	Group identification

[a]Derived from *Hazard Survey of the Chemical and Allied Industries*, American Insurance Association, New York, 1979. The items resulted from a questionnaire survey of failures of many plants and operations.

stimulate performance or action. Content identifies the variables that influence desired actions. Process looks at the linkages between content and specific actions and addresses the question of how to tap needs and outcomes to achieve desired actions. Although research studies do not fully support specific theory of motivation, some theories provide a framework for working with people toward desired actions and performance. This section summarizes a few theories.

Maslow Maslow developed a hierarchy of needs. The concept has been quite popular. His theory is a content theory that looks within an individual for variables that effect desired performance. His hierarchy consisted of five classes of needs ranked in importance from low to high. He thought that needs at the base of the hierarchy required satisfaction first. Higher ones became more important as lower ones became satisfied. His five classes of needs in ascending order are:

1. Physiological needs, such as hunger and thirst.
2. Safety needs (primary body needs).
3. Social needs, such as friendship and affiliation.
4. Esteem, including self-esteem and the esteem of others.
5. Self-actualization, such as reaching one's potential.

Research suggests that basic needs do not diminish as they become satisfied.

Herzberg Herzberg's theory is a content theory that looks at work outcomes rather than needs. He proposed two types of outcomes that affect behavior. They are intrinsic factors

and extrinsic factors. Intrinsic factors involve the work itself and recognition of one's work. Extrinsic factors include rewards associated with the work, such as pay, relations with co-workers and superiors and working conditions. Herzberg believed that only attainment of intrinsic factors can sustain motivation toward organization goals. Research suggests that both are important and there are significant differences among people in their preference for types of outcomes.

Vroom Vroom addressed the motivation process. In his expectancy theory there are three concepts. The first is the attractiveness (valence) of outcomes. The theory does not concern itself with specific outcomes. The second concept is the belief a person has about the link between an action and the outcome (instrumentality perceptions). For example, one might feel that achieving some performance deserves a raise. The third concept is a person's belief about the effort required in an activity and the likelihood of successful completion of the activity (expectancy perceptions). In summary, Vroom's expectancy theory states that when a person's expectancy perceptions for an activity are high and instrumentality perceptions linking the activity to attractive outcomes are high, the person will be highly motivated to engage in the activity. Related studies suggest that desired behavior occurs most often if there are rewards every time one achieves a behavior. Occasional rewards are less effective. An effective reward clearly defines the linkage between behavior and reward.

The implication of Vroom's theory and related work is that people become motivated to perform when there are clear linkages between behaviors and rewards. The linkages require consistent implementation. Rewards must apply regularly when people achieve a desired behavior.

Judgment

Judgment is the act of deciding or discriminating. It is operations of the mind in which one compares information, evaluates values and formulates a decision or reaches a conclusion. One can express a decision or conclusion verbally or through an action. Formulating judgments or reaching decisions can occur quickly and deliberately or extend over time. One may rely on information available from memory or draw on carefully compiled data from various sources.

People differ in their ability to make judgments. In some situations, quick judgment and decision-making are critical. In making quick decisions, one relies heavily on previous knowledge and experience available from memory. If someone has a rich background of knowledge, experience, and compiled information, it is more likely that an action taken as a result of a judgment is a desirable action.

To be successful at a high level, individuals involved in sports must have the skill to formulate good decisions quickly. That requires much knowledge and experience and the ability to recognize and process the dynamics of the sport. Top athletes spend hours in situational training to improve their ability to make good decisions based on what is happening in the current situation.

In many accidents there are similar components. One may have limited knowledge about what can go wrong. One may have little or no experience with emerging situations. One may not recognize what might or is happening. As a result, individuals make poor or incorrect decisions.

Emotion

People are not robots. People have feelings and emotions. People may experience emotions internally or exhibited them through actions. Behavioral literature describes many kinds of emotions, including joy, fear, anger, grief, guilt, pride, love, hate, pity, and anxiety. Situations at home or work may generate emotions. Associations and interactions with others may trigger emotions. Emotions may generate acceptable or unacceptable actions. In many situations, people must control emotions and their expressions. Also important are controlling conditions, situations and interactions that generate emotions. There are both disruptive and facilitating emotional responses.

A variety of approaches can reduce situations that trigger emotional behavior. One simple approach involves effective communication. Another is managing interpersonal relations.

Attitudes, Opinions, and Beliefs

Attitudes, opinions, and beliefs are much the same. They are sentiments that someone forms about something or someone. Someone may also hold attitudes about groups of people, social institutions, topics or issues. Attitudes may be positive or negative. They are usually enduring and slow to change. In some cases it is possible to infer a person's attitudes from their actions in certain situations and from verbal statements.

Formal assessment of attitudes involves the use of carefully developed survey instruments. An attitude survey has many statements about situations or actions with which respondents agree or disagree. Survey results provide a picture of attitudes held by individuals or groups regarding situations covered in the survey.

Attitudes may link to behavior. For example, one may have attitudes about another person, such as a supervisor. Attitudes may not predict behavior. In some cases a person may know an action will have bad effects, but continue to do it. Some call this cognitive dissonance. An example is a person who knows that smoking can lead to heart and lung disease, but continues to smoke.

Individuals may have attitudes, opinions, and beliefs about safety or certain aspects of safety. A safety specialist

will need to understand them and develop strategies for changing them to improve safe behaviors.

Individual Differences

People are not alike. They differ in size, shape, strength, reaction time, physical condition, health, and physiological performance. They differ in ability to perform actions and in knowledge, skills and abilities They differ in the ability to form judgments and make decisions. They differ in attitudes and beliefs, in emotions and in other ways.

Individuals differ within themselves. They do not behave the same in every similar situation. Factors can change their behavior over time.

Some differences are variable. Some differences take care of themselves. The heart and respiratory rates elevate when people exercise. After resting, their physiological responses return to normal.

In other cases, people change through various means. Training, increased knowledge, and expanded experience can change someone performance. Medication may cause changes physically or behaviorally.

Individuals differ from others. They are not all alike. Individuals differ with themselves and change over time. They do not behave the same at all times.

31-2 HUMAN BEHAVIOR AND SAFETY

Safe Behavior

Chapter 3 discussed the idea there are two main causes for accidents: unsafe conditions and unsafe acts. Most of this book deals with unsafe conditions, their recognition and control. A significant part of the accident prevention formula addresses safe behavior and avoiding unsafe acts. Why do people perform unsafe acts? How does one prevent unsafe acts from occurring? These are behavioral issues. Understanding human behavior gives clues to managing behavior.

The Three Es of Safety concept in Chapter 3 suggests some approaches for preventing unsafe acts. Education, enforcement, and engineering all have a role. Enthusiasm, a fourth E, has a role, too. Also, there are other concepts that apply. Chapters 32 addresses procedures, rules, and training. Chapter 36 discusses safety management systems.

Education and Training People learn many behaviors. There is informal learning and formal learning. Studies suggest that by age 6 people have acquired half their knowledge and skills. Children learn to walk and talk by trial and error. They get a reinforcement from those around them. Higher concepts and abstract learning usually occur in school. Education and training provide the knowledge and skills people require to act safely. Much of safety education and training is specific to work, equipment, job tasks, and a variety of situation. Safe workers need specific knowledge to perform safely.

Experience Experience is another form of learning. In sports, a lot of training focuses on learning by experience. Players must be able to recognize game situations and act in response to ongoing play. The same is true for effective safety behavior. The more experience someone has with developing situations, the better they react. More likely, their actions will be safe ones if they have experience. Chapter 32 discusses contingency training that helps people learn by experience. In some cases, computers can simulate harmful situations and allow people to learn how to react safely to developing conditions.

To avoid accidents and injuries, one must first recognize dangers in a situation. Not everyone brings the same knowledge and experience to a situation. Not everyone will recognize or perceive a danger that may be inherently present or may develop. For example, some workers may not recognize that a guard should be in place on a machine because they have no experience with the equipment. They may not recognize a danger or know what protection is appropriate.

In another case, a dangerous situation develops rapidly. For example, a child may run into the street after a ball. A driver first sees the ball and anticipates from previous experience that a child may follow. The driver may slow at the sight of the ball. When the driver then sees a child near the curb, the sight reinforces the braking action.

After recognizing a danger, individuals must act to protect themselves against an accident and possible harm. Training will provide the knowledge about the correct and safe actions. Experience through practice will help ensure that safe action occurs quickly

Enforcement Enforcement involves formalized rules and procedures and following them. Without written procedures, people must make up their own behaviors. A safe organization is one that has written procedures that address current tasks, equipment, and conditions. The procedure needs frequent updates to reflect changes.

Compliance can depend on self-discipline after training. More often, enforcement involves someone else observing and critiquing the actions of others. Usually, this is a role for a supervisor. That is why some safety principles place the first line supervisor at the key person in achieving safety in a work group.

Positive enforcement is best. With enforcement there may be some consequence for not acting properly. For example, one company gives drivers responsibility for their vehicles. Failure to drive properly without protecting the safety of others results in loss of that job. Unsatisfactory performance of tasks can lead to both positive and negative outcomes defined by management.

Engineering In many cases, engineers can create designs that prevent certain behaviors from occurring at all. Effective designs for safety eliminate many forms of unsafe behaviors. Others limit the safe behaviors required. A later section of this chapter discusses the engineering role of designing equipment, processes, facilities, and vehicles for safe use. Chapter 33 considers human capabilities and limitations and designing for human performance.

Communication

Communication is an important part of education and training. People cannot perform correctly if someone has not told them how to perform safely, what dangers to look for, and what procedures to follow. Communication may involve training classes, instructions, job feedback by supervisors, training videos, computer programs, published procedures and rules, warnings and instructions. They may even involve simulations and experience development. One cannot expect people to decide and act on their own. They need the knowledge, skills, and experience to recognize a dangerous condition and know appropriate actions as situations develop or to prevent harmful results.

Feedback

Feedback is knowledge of results. Feedback is an essential ingredient in learning. Instructors must reinforce correct behavior to greatly enhance knowledge of results. People need to know if they perform tasks correctly and safely. They also need to know if they perform tasks incorrectly. Safe behavior requires feedback and reinforcement. For example, feedback on wearing of personal protective equipment, a safe behavior, helps gain user cooperation.

There are several methods for giving feedback. One method is verbal comments from someone else, such as a supervisor or manager. Feedback may involve formal performance reports about behaviors. For example, a performance report may contain the number of parts produced, number of errors or the accident rate. Feedback may include awards or rewards.

If individual performance is important, individuals should receive the feedback. If group performance is important, feedback should go to the group. In some cases there is a need for feedback to both individuals and groups.

Generally, immediate feedback is better than delayed feedback. Performance may involve short increments or small elements. Feedback on such small components is usually better than waiting to give feedback on longer tasks and actions. Feedback should be precise. If a particular task or component of a larger action is critical, feedback should reflect correct or incorrect performance of that component. Reinforcement should be as often as practically possible.

Critical Incident Technique This is a method for direct observation of human behavior that is critical and important. A critical incident may a positive or negative activity. Some have used this approach in observing important or critical safety procedures. The approach provides a way to create feedback for the activity.

One study provides an example. The study involved small construction contractors.[1] For about a month workers created logs of critical incidents on the day they occurred. The researchers analyzed the incidents and developed feedback for employers and workers. The feedback addressed training and other factors that could reduce such incidents.

Job Safety Analysis

Job safety analysis (JSA) is technique to help identify what behaviors in an operation are safe and correct. It is a form of task analysis. Some call the procedure job hazard analysis.

The procedure begins by breaking an operation into tasks or activities of workers. The analysis continues by identifying the hazards associated with each activity. The analysis also identifies how to do the tasks correctly and safely. Before finalizing the information, the procedure may draw on the experience of several people who know the operation well.

There is a variety of formats for documenting the analysis. One example appears in Figure 31-1. When final, the hazard analysis and recommended practices can become part of an operating procedure, user manual, or training program.

A job safety analysis may be part of other forms of task analysis common to industrial engineering practice. Engineers often consider work flow, motion economy, time associated with each job task, eye and hand or foot movements. Their goal is to find more efficient ways of completing operations. A side effect of job safety analysis is helping to find less hazardous ways of completing work and helping to improve operational performance.

A JSA should consider abnormal activities and conditions, not just normal, routine operations. The unusual situations include those leading to accidents and injuries. Non-routine activities often involve cleaning and maintenance. Because these are less frequent and operations do not always consider such activities, they may produce accidents more easily. People often make the wrong decisions or take the wrong course of action in adverse situations. JSA for non-routine operations can also lead to design improvements that increase safety and reduce hazards.

Risk-Taking Behavior

Many factors influence whether someone will take risks when performing activities. Some people are reluctant to do certain tasks because of potential harm. Others may perceive the risk associated with a behavior much differently.

WORKSHEET FOR JOB SAFETY ANALYSIS	Job		Analysis by
	Supervisor	Analysis Date	Reviewed by
	Department	Work Group	Approved by
Brief description of job			
PPE required for all tasks (special PPE noted for individual tasks)			
TASK OR STEP	HAZARDS	SAFE JOB PROCEDURES	

Figure 31-1. Example of a job safety analysis worksheet.

Chapter 34 will address many aspects of risk as it relates to achieving safety. The concept of risk taking is important when trying to understand human behavior.

Biorhythms

Some behaviorists in the nineteenth century suggested that people have cyclical rhythms that influence behavior. People in a number of countries follow this premise and confirm the theory with their own behavior. The theory of biorhythms claims there are three rhythms that originate at birth. The three are physical, emotional and intellectual. They have 23-, 28-, and 33-day cycles, respectively, depicted by sine waves. Each cycle has three phases: positive, negative, and transitional. The theory claims that congruence of the periods affects events, moods and actions of a person. One can easily find biorhythm calculators online. Do not confuse biorhythms with biological rhythms, such as circadian rhythm.

A number of companies conducted studies to determine if biorhythms influence the likelihood of accidents. Some claim significant results. Others show no relationship at all.[2] Studies that found significant relationships may have confounding elements in the protocol used. Overall, studies have not found consistent results to link biorhythm theory to accident prevention.

Alcohol and Drugs

Alcohol and drugs contribute to accidents and injuries. There is a strong relationship between motor vehicle deaths and blood alcohol levels of drivers. Similarly, fire deaths and blood alcohol have strong links. Increasing levels of blood alcohol have strong links to behavior. People lose the ability to make sound judgments and quick decisions. They respond more slowly to stimuli. Their motor skills diminish.

Employers face problems of employees drinking on the job or coming to work with alcohol in their blood. Results of one study indicate that employees who abuse alcohol are absent 16 times more often than those who do not. They receive three times more sick leave. They have four times the accidents and are five times more likely to receive workers'

CASE 31-4

November 19, 2011, Dundee, Scotland. A train conductor stepped from a car during a passenger stop. He did not notice until it was too late that his train doors had closed and locked and his train was pulling away, leaving him on the platform.

Follow-up investigations revealed that he had three times the blood alcohol level allowed. Regulations restricted the blood alcohol for individuals responsible for train operations. The conductor resigned from his position.[a]

[a]www.dailymail.co.uk/news/article-2076636/Drunk-conductor-left-standing-platform-train-pulled-away-him.html

compensation. Some employees regularly screen employees for alcohol, especially if the position has significant impacts on the safety of others. Examples are train engineers and pilots.

Both street drugs and prescription drugs can increase the likelihood of accidents. When any drug reduces physical or mental performance, the chances of error, poor judgment and accidents increase. Some drugs, such as antihistamines, may simply cause drowsiness.

Many companies have programs to assist employees with alcohol and drug problems that affect their work and the loss and claims rates. Some employers use drug and alcohol screening programs during hiring. Some use random screening during employment. For some jobs which can affect the safety of others, laws may require drug and alcohol monitoring.

Workplace Violence

Workplace violence is any act or threat of physical violence, harassment, intimidation, or other threatening disruptive behavior that occurs at a work site. It includes verbal abuse, physical assault, and homicide.

Contributing factors are exchange of money with the public, working with volatile and unstable people, working alone or working in isolated places. Other contributing factors are working where alcohol is served, working late at night or in high crime areas. Workplace violence is higher for people involved in human interactions with the public. Occupations with elevated risks include retail, medical and social services, law enforcement, or working alone such as taxi drivers.

For 2013, Bureau of Labor Statistics data indicate 753 workers killed through violence. Those included 397 homicides and 270 suicides. These cases amounted to 17% of all work-related fatalities.

One step toward prevention of workplace violence is instituting a strong policy that has no tolerance for workplace violence. The policy should cover workers, patients, clients, visitors, contractors, and others who come into contact with employees. Particular preventive actions come from hazard and risk analysis and identifying factors that may contribute to violence cases and conditions. Another approach is training employees to recognize potential violence and to understand risk factors for violent behavior. OSHA offers some publications to help deal with workplace violence.[3]

31-3 DESIGNING FOR HUMAN BEHAVIOR

There are many ways to remove or reduce hazards through design. Sometimes engineers forget to consider user capabilities and limitations, user behavior and the *use environment* (Chapter 7). Understanding people and their behavior is an important consideration in design.

For example, running a pipe along a floor surface creates a tripping hazard. It does not make any difference whether the activity near the pipe is a production activity or a maintenance and repair activity. The probability of an accident during maintenance and repair may be lower because access is less frequent than a production activity. However, the tripping hazard remains. Any person walking or working near the pipe must avoid falling over it. That requires recognition of the hazard and specific behavior to step over it. Good design would not place the pipe on the floor and create a tripping hazard.

Design problems may be even more subtle. A change in surface friction properties may create a slipping hazard. A person may initially walk on one surface. The person gains a feel for the resistance underfoot. Suppose the person encounters a sudden change in a floor surface that is more slippery. The person may not notice the change and the need to adjust the gait. The stride may be too long and lead to a foot slipping out from under the person The result is a fall.

Similarly, a sudden change to a high friction surface can require adjustments. Failure to adjust may lead to a fall forward. The second surface may prevent movement between the shoe and the surface.

Designing for human behavior must anticipate *foreseeable* activities (see Chapter 7). Designing for foreseeable behavior requires knowledge of what people do in various circumstances. For example, it is not enough to safeguard machines for normal operations or production use. A designer must also protect workers involved in cleaning, setup, and maintenance. In many cases a designer can reduce hazards by incorporating features that are less dependent on people protecting themselves. A designer may include

features that eliminate the need for behaviors that could lead to accidents.

Designing for people must anticipate a range of ages and capabilities. Will the users be able-body adults? Will the users have disabilities? What might the disabilities be? Could the users also be children? Will users be large or small? Will users be men or women? What are the capabilities and limitations of the potential users? The field of human factors engineering or ergonomics addresses many of the capabilities and limitations of people. This field suggests how to design with those considerations in mind. Chapter 33 discusses ergonomics.

Dealing with these design problems requires analysis to identify the potential behaviors and errors in behaviors that can lead to accidents and injuries. Techniques to identify these behaviors include job safety analysis (JSA) or some derivative of it. There is a need to conduct tests of designs with users who represent the population of potential users.

31-4 SAFETY AND COMMON SENSE

Some people have the notion that safety is nothing more than a lot of common sense. There are many problems with this approach.

What is common sense? The dictionary says it is sound, ordinary sense, or good judgment. Common means a characteristic shared by a group at large. It is a characteristic belonging or applying to a community at large. Sense means sound perception or reasoning or correct judgment. It means the ability to perceive or discern. It infers sensibility or a quick reaction to actions of objects or others.

The ability to perceive and recognize hazards is important in achieving safety. To take corrective action, people need an ability to recognize a danger in a rapidly developing situation. People need knowledge to anticipate what is going wrong. People need skill in making good judgments or decisions about corrective actions to assure their safety.

One problem with common sense as a basic premise for safety is that human capabilities for achieving safe behavior are not universal. Individuals vary in their training, experience, knowledge, skill, and ability to recognize hazards, perceive dangerous situations in a timely manner, make sound judgments, and take the correct protective action without error.

Most people would agree that children do not have common sense. When does someone get common sense? How can you tell if someone has common sense? There are no methods for measuring common sense.

Leaving safety to common sense suggests that somehow safety in a complex society will result if people pursue their own safety. Accidents are caused. Safety is achieved by thorough analysis, good design, and solid development of knowledge and skills through training and management. It is not an innate characteristic common to society. The desire to be safe is common. The actions required to achieve it are not.

31-5 TECHNOLOGICAL ILLITERACY

Another behavioral problem facing highly technical societies is that most people do not understand the technologies that are part of their everyday lives. They do not foresee what hazards a technology may have or present. There are only a few people who have the knowledge of many technologies and associated products to know the hazards a technology offers. While people depend on technologies, most do not know what dangers they present. Many do not know how to use technologies safely because they lack the knowledge or skill required for the technologies. This is the problem of technological illiteracy. More and more people depend on the producers of products and employers who have specialists to assure safety. Users remain technologically illiterate.

For example, an average person who is cleaning something does not understand the chemistry of soap, solvents, acids, and alkaline materials. It is not uncommon to find people mixing different cleaning agents to gain more cleaning power. Too often the result is an accident and injury from a chemical reaction.

Many people do not understand mass, moments, inertia, potential, and kinetic energy, or conservation of momentum. They wonder why they were unable to stop a falling object. They fail to recognize the danger of walking under a suspended load. They fail to see the danger of bicycling on the same pavement with 3,000 lb vehicles moving only inches away at speeds three or four times faster than their speed. Lobby groups push lawmakers to make trucks 20–30% larger. Then the same lawmakers create rules that make passenger vehicles smaller.

Two national surveys that explored the technical knowledge and skills of the American population found that technological illiteracy is significant and somewhat related to literacy in general.

Fifty percent of American industrial workers have math skills at or below the eighth grade level. Twenty-eight percent of people cannot make correct change when given a cash register receipt. Thirty-three percent of the respondents to one survey did not know how a telephone works, even though the device is much older than they are. Nineteen percent felt they had little understanding of radiation. Forty-one percent felt that rocket launchings and other space activities have caused changes in our weather. Twenty percent felt it was not wise to plan ahead, because many things turn out to be a matter of good or bad luck anyway.

Problems are compounded by the fact that illiteracy, including technological illiteracy, is highest among the poor and uneducated. Studies indicate that those most affected by disasters are the poor and poorly educated. They suffer the

greatest losses. Perhaps there is a relationship between technological illiteracy and loss rates.

Given this context, designers have a challenge. They must make technology and technology-based products, systems, and environments safe. Designers and employers have responsibilities for many who have little or no understanding of their designs. Recognition of hazards, making judgments, and taking corrective actions cannot be left to untrained users. Moving technology to Third World countries places even greater portions of a population at risk if safety is not integral in products, or if workers and communities do not receive training for them.

31-6 JOB STRESS AND OTHER STRESSES

Another aspect of safety related to human behavior is job stress. Physical disorders that stem from behavioral problems, such as anxiety, fear, and other forms of psychological stress have the name psychosomatic disorders. The psychological conditions manifest themselves in physical disorders of various kinds.

Job stress is becoming more important in safety. It appears to increase with the increase in the number of high-paced, demanding jobs. In addition, more and more claims for job stress receive worker compensation. Job stress is common in management positions. However, it occurs in many other kinds of positions as well.

Various conditions or situations in our lives cause our body to react. A scare causes an increase in heart rate, an increase in blood pressure and secretion of adrenalin. A scare may cause someone to sweat.

Job situations may produce similar effects in the body. Certain tasks may be difficult to perform and produce stress-related reactions. There may be deadlines to meet, difficult social situations, difficult to handle co-workers or presentations to make. All of these may produce similar responses. Continued stresses and chronically complex and difficult work situations may lead to more severe health problems. Researchers identified major events in life related to subsequent illnesses and assigned weightings to these events. Table 31-2 contains a test for evaluating the likelihood of becoming ill from major stress events in life.

Stress may be positive or negative. The body's reactions to stress help us concentrate and perform. Some people do better under pressure. When there is no opportunity to relax or escape from stress conditions, stress can be negative and lead to reduced performance and health problems. The term burnout has associations with prolonged job stress. A number of factors contribute to job stress. Included are:

- Not enough time to complete a job.
- Lack of clear direction and goals.
- Lack of clear instruction.
- Absence of recognition or reward.
- Lack of opportunity to participate.
- Responsibility without authority.
- Prejudice and bigotry.
- Poor interaction with others due to differing goals and values.
- Unpleasant or dangerous work conditions.
- Lack of control over job performance.
- Job insecurity.

There are several techniques people can use to help reduce and manage stress. First, they must recognize the situations and conditions that lead to stress. They need to sense the body reactions that are symptoms of job stress. Applying one or more relaxation techniques can help reduce stress. A deep breath or simple exercises followed by relaxation can help. Another technique is getting away from certain difficult situations. Modifications in lifestyle, such as exercise, may also help. Some people find meditation helpful.

31-7 MANAGEMENT PROCESSES

Management methods can affect how people perform or an organization performs. Management methods also affect the culture of an organization, referring to how people in the organization approach work planning, organization and execution. The reader should refer to the wealth of literature on effective management methods. This section will touch on a few concepts and approaches and how they may influence performance, including safety performance. Chapter 35 provides more details on safety management systems.

Total Quality Management and Six Sigma

A more traditional organizational structure found in U.S. companies and organizations was a top-down approach. The organizational structure had multiple layers between the top leader of the organization and the lowest level worker. Before the age of computers and the internet, the layers of management provided a path for directing what was to be done down through the organization. The layers also helped communication up through the structure. The layers monitored and reported on accomplishments. Many organizations continue to use such an approach.

In the 1990s, most U.S. organizations eliminated many of the layers in the top-to-bottom structure. In part, the change resulted from the use of personal computers and the Internet. Higher levels did not need many of the intermediate layers to analyze and process information into a form for the next higher level. Someone at any level could access

TABLE 31-2 Life Stress Scale[a]

Instructions
1. In the table below, check those events that occurred to you in the last 12 months.
2. For each item checked, insert the value for that item in the Score column.
3. Sum all entered scores.
4. Compare your score to the following:

Total Score	*Probability of Becoming Ill*
< 150	37%
150–300	51%
> 300	80%

Event	Value	Score
Death of spouse	100	—
Divorce	73	—
Marital separation from mate	65	—
Detention in jail or other institution	63	—
Death of a close family member	63	—
Major personal injury or illness	53	—
Marriage	50	—
Being fired at work	47	—
Marital reconciliation	45	—
Retirement from work	45	—
Major change in the health or behavior of a family member	44	—
Pregnancy	40	—
Sexual difficulties	39	—
Gaining a new family member	39	—
Major business readjustment	39	—
Major change in financial state	38	—
Death of a close friend	37	—
Changing to a different line of work	36	—
Major change in the number of arguments with spouse	35	—
Taking on a mortgage greater than $10,000	31	—
Foreclosure on a mortgage or loan	30	—
Major change in responsibilities at work	29	—
Son or daughter leaving home	29	—
In-law troubles	29	—
Outstanding personal achievement	28	—
Spouse beginning or ceasing work outside the home	26	—
Beginning or ceasing formal schooling	26	—
Major change in living conditions	25	—
Revision of personal habits	24	—
Troubles with the boss	23	—
Major change in working hours or conditions	20	—
Change in residence	20	—
Changing to a new school	20	—
Major change in usual type and/or amount of recreation	19	—
Major change in church activities	19	—
Major change in social activities	18	—
Taking on a mortgage or loan less the $10,000	17	—
Major change in sleeping habits	16	—
Major change in number of family get-togethers	15	—
Vacation	13	—
Christmas	12	—
Minor violation of the law	11	—
	Total	—

[a]T. H. Holmes and R. H. Rahe, "The Social Readjustment Rating Scale," *Journal of Psychosomatic Research*., 2: 213–218 (1967).

information from a common source and software applications provided the same analysis and reports to virtually anyone on the computer network. The change in technology impacted how organizations worked and reduced overhead costs.

The changes in management methods also recognized that a group of people working together is smarter than any one person alone. This type of management method requires a collaborative environment and collaborative work groups.

Another change was the emphasis on quality in order to be competitive in the marketplace. Many organizations rediscovered the work of Juran and Deming on quality and methods for achieving it. There was a national award called the Malcolm Baldridge Award. It recognized the quality improvements of companies.

One name for management systems that focus on quality is total quality management (TQM). There are other names as well. The methods rely on several factors for success. One factor is listening to the customer to identify opportunities to improve. Another factor is recognizing that organizational performance ties to management processes given to workers. It realizes that workers can perform no better than an assigned process allows. Focusing on individual performance did not improve organizational performance.

In contrast, TQM sought participation of everyone in a work group. The group would review the processes it used. The group would identify the opportunities for change that would improve meeting customer expectations and needs and enhancing productivity. With this approach, the metrics for assessing performance changed. Some reduce the metrics to two basic ones. They are process time and errors. Process time refers to how long it takes to complete some function. Process time varies with specific settings.

Delivery time of mail is an example. One may write a letter, put it in an envelope with postage and drop it in an out box on the desk. The addressee may see it several days later. Various steps in the process can affect the total delivery time. How frequently someone picks up mail from the out box impacts the process. How long the letter sits in the mail room before transfer to the post office also impacts the process. Postal service handling and delivery procedures impact the process.

Suppose the daily pickup from an outbox occurs at 9 am each morning, the same time that someone delivers incoming mail. If the sender dropped the letter into the outbox at 10 am on a Friday and the office is closed all weekend, no one will pick up the letter until Monday. It would not move internally in the organization for nearly three days. Walking to the mail room and dropping the letter in the postal pickup box after completing the letter will reduce the delivery time potentially by more than two days. In this process, it would be easy for people to find opportunities to reduce the cycle time and increase the satisfaction of the recipient customer.

Errors, too, can have many definitions, depending on what is meaningful to a work process. In total quality management, the goal is to reduce errors. Errors produce "scrap." They are end products or results that are not useable or do not meet standards acceptable to customers. Errors cause rework that elevates cost. A group can reduce errors by focusing on the management processes. Group members can identify opportunities for improvement and incorporate quality-enhancing steps into the processes. They can reduce error rates. A goal is to get all participants involved in identifying and implementing changes and achieving results. The greater the focus on continuous improvement and the more frequently people review a process, the faster the organization achieves new levels of quality.

In the TQM management scheme, incidents and accidents are errors. They affect product quality and rework. In addition, they make process times longer.

A more recent version of TQM is Six Sigma. Many companies use Six Sigma to make improvements in management processes. The term six sigma refers to six standard deviations from the mean on a statistical normal distribution. It refers to achieving only one error in a million opportunities. Six sigma has emerged as the name for programs devoted to learning quality improvement techniques and implementing them.

Total quality management and six sigma also apply to safety and safe behavior. As noted, incidents, accidents and damage causing events are errors. Incidents, accidents and damage causing events add to process times. A key to reducing incidents, accidents and damage causing events is changing management processes. The way to make improvements is through hazard recognition, evaluation and control. Safety becomes a component of quality. Because quality improvement is a continuous process, hazard recognition, evaluation. and control are continuous. For group members to contribute effectively, they need training in hazards and controls applicable to their work processes.

Use of a TQM or Six Sigma approach in an organization requires changes in the way people plan, organize, and accomplish work. Everyone in the work group can contribute to improving results, including safety. Effectiveness results from broad participation.

Shared Leadership

Another management strategy called shared leadership reflects the change from a top-down management approach. In a top-down setting, an individual at the top of an organization or a work group is the leader. The leader plans, organizes and directs. If the work is complex, no one person has sufficient knowledge to master all of the details of a process. The idea of shared leadership invites members of a group to contribute ideas for improvement. Various group members can take responsibility for leading the rest of the

group in certain aspects of the work. As a result, the roles of people in the group vary, depending on who is leading a particular activity. In one activity a person may have a leadership responsibility and in the next be a participant. No single person is the sole leader.

This approach may help in achieving safety and safe behavior in a work group. The group identifies the hazards, analyzes them, and implements appropriate controls. Their collective knowledge leads to a better and safer operation. Various individuals may help others master the details of their group responsibility.

31-8 BEHAVIOR-BASED SAFETY

Getting workers involved in achieving safety is essential. As noted above, several management methods try to engage managers, supervisors, and workers in improving work processes, including safety. Some hazards remain in each process that pose threats for workers. The workers must help define and assure implementation of administrative procedures focused on safe work.

In the last several decades the role of human behavior for achieving safety has expanded. Psychologists have engaged in applying behavior management methods to safe work and workplaces. There are at least two different approaches.

One approach[4] builds somewhat on concepts found in TQM and related management schemes. This approach seeks to identify key at-risk behaviors. It seeks to engage managers, supervisors, and employees as a team in the process of reducing them.

The process has the name Behavioral Accident Prevention Process. Its goal is reducing the number of costly, at-risk behaviors. The first step is engaging the team in identifying the primary behaviors involved in accidents for their work group. The next step is to review the list by applying risk analysis and the frequency and severity of occurrence. That helps identify the high risk and most dangerous behaviors. Another step is training employees on a team to observe safe and at-risk behaviors of coworkers and providing feedback. They also evaluate what may lead to at-risk behaviors. It may identify a lack of knowledge or issues with equipment or process design. Each of these factors provide opportunities for improvement. The process is continuous, seeking ways to reduce at-risk behaviors and the factors that may contribute to them.

Another approach emphasizes use of task observation by peers and providing feedback as a way to modify behavior. Workers learn how to make observations and provide useful positive and negative feedback to reduce behaviors that can lead to accidents and injuries. In some ways, this approach is similar to the critical incident technique. Some feel that a weakness of this approach is management pushing its responsibility for accident prevention onto workers. Some feel that this approach emphasizes what not to do, rather than reducing risk by training people in safe procedures. That can vary depending on how a work group implements the process.

Some organizations have used behavior-based safety methods successfully. Some have not. To be effective, safety programs need to achieve safe behavior. To achieve that, people in a work group need training on hazard recognition, evaluation, and control. In addition, they need to learn how behaviors that are part of the process can contribute to safety of the work. Getting workers to perform requires broad participation and collaboration among members of a work group. It requires shared leadership within a work team. Instead of placing blame for wrong behavior, participants focus on changes to processes and behaviors. Participants need to understand the role that their behavior plays in the success of the process. This effort works in concert with other safety methods that contribute to continuous improvement of the processes.

EXERCISES

1. Contact a local hospital or clinic. Find out what employee assistance programs they provide for employers. These may include programs to deal with personal problems off the job, alcohol and drugs, stress management, and other subjects.
2. Obtain several accident reports or review several liability lawsuits. Analyze the findings to distinguish unsafe acts and unsafe conditions. Evaluate the cases to determine if designs could have incorporated features that would have eliminated the unsafe acts or removed the harm from such acts. Identify if administrative procedures could have prevented the accidents.
3. Work with an organizational unit to apply quality methods to its processes and identify how to incorporate safety into the processes.

REVIEW QUESTIONS

1. What are two classes of behavioral theories?
2. Briefly explain the following motivation theories:
   (a) Maslow
   (b) Herzberg
   (c) Vroom
3. Briefly characterize the following:
   (a) judgment
   (b) emotion

(c) attitudes, opinions, and beliefs

(d) individual differences

4. Name three things that can help prevent unsafe behaviors.
5. Why is communication important for safe behavior?
6. Why is feedback important for safe behavior?
7. How can performance feedback be most effective in achieving safety?
8. Explain job safety analysis.
9. What are biorhythms? Are they predictors of accidents?
10. How are alcohol and drugs related to accidents and unsafe acts?
11. What role can engineers play in preventing unsafe acts?
12. What is common sense? Is it the basis for safe behavior? Explain.
13. What is technological illiteracy? How is it related to safe behavior?
14. What is job stress? How can someone manage it?
15. Explain how management methods have changed. Explain how management methods can help achieve safety.
16. What is behavior-based safety? How is it tied to process improvement?

NOTES

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CHAPTER 32

PROCEDURES, RULES, AND TRAINING

There are several techniques for managing, controlling, and changing human behavior. The goal is to help people make their actions safe. A key approach is training. However, proper actions in an organization begin with policy. Then, policy must lead to written procedures. Organizations implement procedures through instructions, warnings and training. Supervisors can reinforce safety behavior through feedback of various kinds.

Although procedures and training are important in achieving safety, they do not remove hazardous conditions. Procedures and training help people recognize hazards and achieve safety.

32-1 POLICIES AND PROCEDURES

Policy

Policies are statements of goals, objectives, and operational principles that govern an organization. Often those at the top of an organization create and approve policies. That may involve a president, chief executive officer, board of directors, or someone else with authority at the highest level. High-level policy usually defines basic principles and practices of an organization. Normally, organizations publish policies in writing or electronically throughout the organization.

A policy manual is the collection of all policies formally adopted by an organization. Policies get top management to subscribe to, endorse, and support major operational provisions of an organization. Policy statements tell all members of an organization what is important, what they should achieve, and how to act. Each policy statement may have accompanying explanations, variations, exceptions and interpretations for critical or complex situations.

Safety Policies Part of a policy manual is safety policy. Usually, it starts with a statement placing safety as one of the top priorities of the company. The statement may identify safety for employees, customers, visitors, and the community. The policy may cover operations, practices, products, and services. It may state overall safety goals.

Policy details may delegate authority and responsibility to work groups, supervisors, and others. Details may reach to specific practices, such as who can sign permits or make decisions in emergencies. Safety policies may include a short list of company rules that apply to everyone.

A policy may point to a company safety handbook that covers details for each organizational unit or operation. Safety policy may identify organizational units or individuals who provide expertise and help with safety implementation. It may establish safety committees and define their responsibilities.

Like all forms of policies, safety policies require periodic review and updates. Some may require legal review.

Safety Rules

Many companies or organizations have a booklet of general safety rules. Sometimes there is a document containing general rules that employees must follow. Included is a section on general safety rules during company activities. These rules apply to everyone.

Because there are many complexities in safety, many companies have additional rules covering particular safety problems. This may be a company safety handbook or similar document. The handbook may give details about such topics as fire protection and fire response procedures. It may list, cite or define standards that designers, maintenance staff, or supervisors must follow. There may be separate manuals for design and maintenance personnel and particular operations or departments. The handbook may collect all safety manuals and operating procedures into one document system.

Procedures

Procedures are details for implementing policies. Procedures give step-by-step information about what to do and how to complete particular situations. They identify who does the steps. They specify when actions apply. Procedures may cover routine operations or non-routine tasks. Many call procedures that apply to routine activities *standard operating procedures* (SOPs). Examples of non-routine activities are

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 32-1

A training procedure for pilots failed when it did not incorporate changes resulting from new models of an aircraft that was part of the company fleet.

An airplane had four engines. If there was a failure in one engine, the pilot had to verify which engine had failed. Aircraft produced early in production were Model A. Later, some changes were made to the same aircraft. Those changed aircraft were Model B.

For Model A, the procedure for verifying the failed engine required the pilot to shut down all four engines and restart them one at a time. The procedure identified which engine had failed.

For Model B, the verification procedure changed. The pilot shut down and restarted one engine at a time.

In-flight pilot training for the company normally involved a Model B aircraft. However, in ground training, pilots had to learn procedures for both Model A and Model B.

During a training flight the instructor introduced a simulated engine failure. The student pilot applied the verification procedure for Model A. The aircraft crashed. The in-flight simulation procedures were not updated after the company began using Model B for flight training.

those involving emergencies, maintenance, and repair. There are also special procedures that require detailed explanation and emphasis. Examples of special procedures are those dealing with exceptions to routine and non-routine procedures.

Keeping Procedures Current If there is a change in a process, operation, or equipment, associated procedures will likely need updates. Frequently, changes affect safety practices. Obsolete procedures may cause participants or users to perform unsafe actions. The wrong action may lead to an accident or injury. Procedures involving operations with serious consequences must be current.

All participants need to know about changes in procedures. It may be important to implement the change for everyone at the same time so different procedures are not in place. The change-over will require detailed planning for successful implementation. People using new procedures will need feedback to reinforce the changes.

Standardization Sometimes there are several machines that perform the same function. They may not work exactly alike. Someone operating one machine may learn safe procedures for that machine and not know about differences on another machine. Different operators may learn procedures differently. It is best to find ways to make machines, operations and equipment operate alike. It is good practice to have all people doing the same work learn alike about doing tasks the best way. That is standardization.

From a business perspective, standardization can often reduce errors and lost products or production. From a safety perspective, standardization can reduce the potential for errors that lead to accidents and injuries. Of greatest importance are those tasks and operations that can have serious impacts.

Standardization involves many elements. It means that sequences of operations, controls, displays, procedures, equipment and other elements are identical across systems, Standardization means that workers all learn to perform tasks the same and understand the underlying concepts and principles.

Achieving standardization requires collaboration among workers and their leaders. There may be reasons why people do things differently. The process for achieving standardization must uncover the differences among operations, equipment and procedures and the reasons for the differences. Participants must help ensure implementation of standardization, especially when they must change their behavior.

CASE 32-2

March 28, 1979, Three Mile Island, PA. Following the accident at the Three Mile Island nuclear power plant, investigators found several kinds of incompatibilities between control panel displays and patterns of behavior people had learned. A fundamental concept learned across most societies is the meaning of red and green: Red means stop or danger; green means go or conditions are satisfactory. One arrangement of status lights and controls violated this pattern and led to wrong interpretation and action.[a] (Refer to Chapter 33 and *population stereotypes*.)

[a]B. Sheridan, "Human Error in Nuclear Power Plants," *Technology Review*, February: 23–33 (1980).

Levels of Procedures It is wise to organize some procedures into different levels. Difficulty or complexity of tasks, frequency of tasks, or level of authority involved may define approval levels. For example, daily startup of equipment may need a pre-energizing inspection and preliminary tests before the activity moves into full operation. Employers can train workers to perform such normal safety checks.

For example, most commercial airlines use five levels of approval procedures when returning an aircraft to service following a repair. The goal is to ensure that someone knowledgeable approves a repair and the safety of the aircraft. The risk to flight dictates the level of approval. Minor repairs, such as changing a burned-out instrument panel light, use local approval. Major repairs require high level approval.

However, if there is a failure or the equipment shuts down from an unsafe condition, there may be a second-level procedure. It may require a supervisor with advanced knowledge to evaluate and concur in the problem. In addition, after completing repairs the repairmen and supervisor must approve the work. Then the equipment can return to full operation.

A major failure or shutdown may require a third-level procedure. Such an event may need specialists to diagnose the problem. Later, the specialist may need to approve repairs and assure that everything is safe. Then the process can begin again.

The second and third-level procedures may require special tests and testing equipment, rather than observation alone. The additional participants will bring additional knowledge and experience to the problem. They may also bring specialized safety knowledge important for returning to full operation.

Analysis for Procedures

Developing procedures begins with an analysis of the tasks or activities of an operation. One can use various forms of task analysis. Involved processes and complex equipment may have applied advanced engineering analysis during development. Engineers may have used analysis to make cost estimates or production planning. Those analyses may help when working on safety considerations.

The focus of safety analysis is identifying hazards associated with each step or task. The analysis may uncover whether a task requires workers to perform unsafe acts. To complete a safety analysis, the procedure should indicate what control each hazard needs and how to preform tasks safely. The analysis should clearly identify any hazards which remain.

A very common form of safety analysis is Job Safety Analysis or Job Hazard Analysis. Chapter 31 discussed this procedure. Figure 31-1 illustrated one format for job safety analysis.

In analyzing an operation, it is necessary to consider two kinds of sequences. Analysis starts with how a process works correctly. Analysis should also consider what can go wrong and how to proceed safely with such events. Those conducting analysis need to forecast what can go wrong. The analysis must identify resulting hazards of abnormal events. Too often, injuries occur when people take the wrong action during unusual events. Chapters 36 discusses other useful methods.

Results of analysis help organizations decide about unplanned events and to develop procedures that minimize danger. Procedures should explain normal or general operations first and then discuss the exceptions, abnormal operations or special conditions.

Special Procedures and Permit Systems

Special safety procedures include those dealing with emergencies and abnormal or very dangerous situations. Not only should these procedure cover how to prevent injury or property damage, they should identify any changes in who is in charge. They must explain who has authority and responsibility during abnormal situations. For example, during a fire, the fire chief or ranking firefighter takes charge of the situation, makes the decisions and issues instructions others must obey. If a worker sees that a process goes wrong and becomes dangerous, the worker should have the authority to shut the process down immediately. They need training in those responsibilities.

Special procedures should anticipate errors in judgment and action and explain correct behaviors. Special procedures covering abnormal conditions should explain what not to do, explain the consequences of that action and why. They must identify the right course of action and explain why that is best.

Permit Systems A common form of special procedure is a permit system. A permit system recognizes that some conditions may be unsafe for particular activities. Someone must evaluate a situation and ensure activities are safe and then approve starting the activities.

Three very common permit procedures are a hot work permits, confined space entry permits and lockout/tagout procedures. Consider permitted confined space entry. The goal is to make sure that everything is safe before a permit allows activities to proceed. Both the person normally responsible for the work area and its conditions and the supervisor of people entering the area to perform work must sign the permit. Both attest to the conditions being safe. They agree that the work plan provides for safe operations. In some cases, a specialist may have to evaluate the area, make tests, and sign the permit as well.

Because conditions may change, permits cover limited periods and expire at the end of the approved period. The permits may apply to a specific activity, one shift or one work day. Then those signing must evaluate conditions again and sign a new permit attesting to safety.

Authorized Individuals Other kinds of special procedures are those that are unique to certain activities. A worker must know the procedures before gaining authority to perform them. An employer may have procedures for training and testing individuals before they allowing them to do the tasks.

Hand signals provide an example. There are special signals used by ground crews to guide pilots maneuvering planes on a tarmac and when parking at or leaving a gate. There are special hand signals used to guide crane operators while maneuvering a load. There are special hand signals for guiding excavation equipment operators. People need to learn the signals. Procedures may require passing tests of hand signal knowledge.

Lockout and tagout procedures are special procedures for working on normally energized equipment. The energy may involve electricity, steam, mechanical, or other forms of power or energy. Employers must ensure that any individual involved with a lockout/tagout procedure knows the details of the procedure.

Signatures Many safety procedures require someone's signature. Signatures have meaning. They link decisions and actions to individuals who accept them. Often procedures require multiple signatures. Signatures mean that those signing approve the completed work. Signatures mean that someone responsible accepts a return of authority for an interrupted or repaired process or equipment. Signatures often attest to the safety of a process or equipment. A signature may verify that someone has read and understands a written statement or document. A signature may verify that the person completed an independent evaluation of work, conditions or processes. A signature may attest that equipment is safe to use.

It is easy to defeat a permit system. Those responsible for signing and approving procedures can abuse their responsibility. Sometimes people simply sign a permit without completing an independent assessment of the conditions or work they approve. They do not assure protection for those involved. By failing to provide due diligence in their signature responsibility, they are negligent.

Signatures are common for confined space entry permits, hot work permits, lockout/tagout procedures, and other safety procedures. Before restarting a process, a signature of the person in charge will mean he approves and accepts any repairs or changes.

32-2 WARNINGS AND INSTRUCTIONS

Procedures must incorporate warnings and instructions. Warnings and instructions are important elements of procedures. Warnings identify what dangers exist in equipment or operations. Warnings cover dangers in normal and abnormal or routine and non-routine operations.

Instructions explain how each person involved in an operation is to act and act safely. Instructions explain how people are to protect themselves from the dangers in normal and abnormal, routine and non-routine operations. Instructions need to have a step-by-step format. Steps should use imperative statements and state actions to followed. Too often people write instructions in a descriptive form, explaining how a process works. Explanations are not instructions.

Chapter 7 discussed warnings and instruction for products. Table 7-1 described 15 important characteristics for product warnings. The use of warnings and instructions and principles for preparing them apply to operations as well as products. Without warnings, users or participants may not recognize dangers inherent in an operation. Without instructions, users or participants must make up their own procedures.

There are several standards[1] that address elements of manuals, instructions, signs, labels and related materials. For example, they define four kinds of signal words:

- Danger
- Warning
- Caution
- Notice

They introduce a safety alert symbol that identifies a potential hazard that can cause injury. Figure 32-1 illustrates this symbol. The standards cover safety color codes, safety signs and tags, safety symbols, product safety labels, safety messages, and temporary barricade tapes.

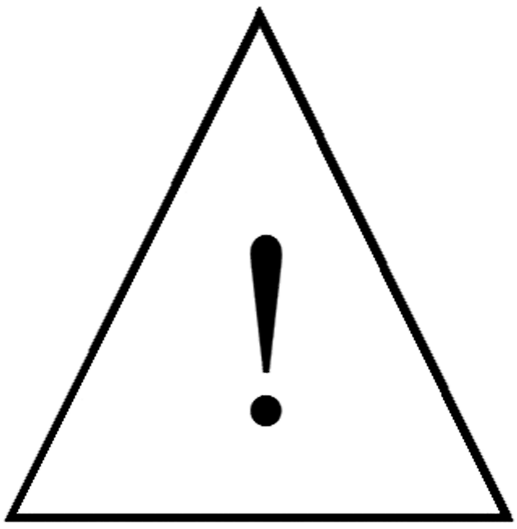


Figure 32-1. The safety alert symbol.

Alarms and Signals

Alarms and signals are one form of warnings and instructions. They are integral parts of procedures. Sensors (sometimes human) must detect a problem and tell people about it. In particular, they must tell people where there is a danger. They should tell people how to act or proceed following the alarm.

In one sense, signals and alarms are instructions to act. However, they are coded instructions, rather than direct, verbal instructions. People must learn what the alarms and signals mean and what actions they call for.

Many alarms and signals are automatic. They have built-in sensors that trigger a light or sound. Some signals, like hand signals for crane operations, are not automatic. They are manual forms of communication.

Today, some alarms and signals incorporate computer technologies. They may have speakers that present automated verbal information or instructions, rather than simply presenting flashing lights or sounds.

Symbols

Symbols are important elements of warnings. They help convey the message quickly and may help those who cannot read the language of the text. A combination of symbol(s) and text is better than either alone. Text is more precise. Some symbols have high recognition and understanding. Within a sample of people, many in a group will recall and understand the meaning of a symbol.

For some symbols, recognition and understanding are low. That is why including associated text is important. Not all symbols have obvious meaning to all viewers. Some symbols are cultural and not understood by those outside a culture.

32-3 TRAINING

From childhood on, people gain knowledge, skill and understanding through training. Training can take many forms and may involve a variety of media. Training is essential for learning how to formulate safe decisions and take safe actions. Through training, people learn to minimize errors that lead to accidents and injuries.

Principles of Learning

Planning and development of training begin with an understanding of how people learn and what contributes to learning. The following list summarizes some principles of learning.

1. *Stimulate multiple senses.* We receive most information through vision. Hearing processes a lot of information, but cannot handle information at the same rate as visual input. Incorporating visual materials into training will help the learning process.
2. *Identify the need for training.* The trainee will understand better if instructors clearly present objectives and strategy for training.
3. *Organize the content logically.* It is better to conduct training in small modules rather than large ones. The material being taught helps determine the logical order. One form of order is proper sequence, where early modules establish the background for later modules. Another form of order is level of difficulty, where easy material progresses to that which is more difficult.
4. *Teach principles with procedures.* People will understand procedures better and retain them longer if an instructor presents first the principle or objective for the procedures.
5. *Teach the whole process first, then detailed parts.* Trainees should learn the whole procedure first. They need to see what each step leads to. Then they can go through the details of the process.
6. *Make sure trainees have time to practice, but keep practice periods short.* When trainees are learning skills and the criterion for success is meeting some performance standard, trainees need time to practice. Short practice periods with breaks are more effective than long practice sessions.
7. *Ensure participation when performance is the goal.* When training occurs in group arrangements, some trainees hold back from participating. An instructor must watch for this and find ways to involve everyone.
8. *Give trainees knowledge of results.* Trainees need to know how they are doing. It is better to evaluate trainees in small increments and give them results of evaluations, rather than delay evaluation and results.
9. *Reward correct performance.* There are many forms of feedback. Positive is generally better than negative. Use praise and verbal comments when trainees do things correctly. Accurate and immediate feedback is better than delayed and general feedback.
10. *Keep trainees interested and challenged.* Instructors can use various techniques to increase participation and interest in subject materials. Ask questions and stimulate discussion. When there are skills involving several people, role playing exercises help maintain interest.
11. *Simulation should duplicate actual conditions.* When simulating procedures and settings, they should accurately represent real situations as much as possible. Unrealistic simulation can lead to incorrect behavior in real contexts.

12. *Students retain unique or unusual material longest.* Use of examples and real situations helps people visualize the subject matter. Dramatic and exotic style may be entertaining, but make sure such activity is meaningful.
13. *Provide relearning to sustain knowledge and skill.* The idea of a learning curve tells us that the more skilled a person becomes, the slower the rate of improvement. Following training, the knowledge or skill achieved by the end of training decays with time. Creating opportunities to relearn, update, or evaluate skills and knowledge will help keep performance at desired levels.
14. *Fit training to individual needs.* Use pretests, interviews, and other evaluations to assess the knowledge or skill of each trainee. Many trainees will have difficulty if there is too great a range in knowledge and skill in the same training session. With self-paced instruction and criterion-based training, individuals can achieve the desired level of knowledge or skill at their own pace. Because each individual works alone, advanced students do not intimidate slow learners or those with elementary skills. Computer-based instruction and training systems allow for customized instruction and repeating of sessions to match the needs of individuals.
15. *Use training modes that fit the learners.* Instructional materials and training methods need to anticipate the audience. Many people today grew up in a visual world. They spent hours watching television since childhood. A new generation is growing up in an age of electronic communication devices. In comparison others grew up with printed communications.

Training Needs

Training programs begin with assessment of need. There are at least two aspects. One aspect considers the importance of training. Do people really need to know and understand something? The other aspect is knowing what level of knowledge or skill people already have. One can review records of employees to see what knowledge, skill and experience they already have. One may observe people on the job to determine if their actions are correct. One can conduct interviews, run questionnaires, or perform tests to determine if the desired knowledge and skill exist.

In some cases, laws and regulations prescribe the need for training. For example, standards of OSHA contain more than 150 training requirements for employees. Other government agencies may also specify employee training. Company policies may define safety training for all or certain employees. The task for an employer is to determine how many employees need the prescribed training and how often. Specific training requirements may not apply to every employee.

Who to Train

Everyone needs training for safety. Within a company there are new employees and experienced employees. There are supervisors and managers and special committees and teams. Product users and the general public need training in safety.

New Employees Accidents occur frequently to employees who are new on the job. Usually, accident rates decrease with job experience. It is essential to train new employees on safety in general and in safety of their job functions. New employees have much to learn, including workplace safety. A session will orient a worker to his new company or new job. Orientation sessions deal with general matters. Most new employees will remember how and when they get paid. They may not recall other details from an orientation session. For safety, it is important to know how important safety is for the employer in protecting its workers. New workers should learn about general procedures in case of an accident.

Sessions separate from orientation should cover details for performing a job correctly. A worker needs instructions in doing a job correctly and safely before starting to work. As early as possible on a job, a new worker need to learn about various situations that can occur. A new worker needs to know how to respond safely to such situations.

During the early phases of employment, new workers need a lot of reinforcement on details of doing the job correctly. There should be review sessions and evaluations to see if the worker understands and applies the training. There should be extra help until the worker reaches a suitable mastery level.

Experienced Employees Experienced employees also need training. One important factor is learning how their work relates to other parts of the organization or to other work groups. Often workers in one work group do not understand how their work can affect the safety of others.

Another important factor is training experienced workers when procedures change. Workers may need to develop skills or know about changes in methods required by operational changes.

In addition, workers need periodic reinforcement on performing work safely. Some workers develop bad habits that may lead to accidents or leave hazards present for others. In some cases work observation and feedback with discussion may correct unsafe practices.

Some laws and regulations require recurring training to help assure safety. For example, many workers require semiannual or annual training about hazardous materials found on their jobs.

Changes in job roles or positions require training for experienced workers. A worker that changes job assignments must learn about hazards and controls for the new tasks.

Supervisors and Managers Supervisors and managers represent company and employer responsibilities. Not only do they need to understand the hazards and controls for their workers, but they need to know what training they must give their workers. They need to understand the regulatory and legal responsibilities for safety that their employer or company bears. They need to know what responsibilities they have under normal, abnormal and special procedures.

A company may have a communications interface with its contractors' work group supervisors or managers. The company leaders need to know the chain of command between the company and its contractors. They need to know how to work between organizations. Supervisors and managers must understand they do not supervise or manage workers of the other organization. Yet, the supervisors and managers play an important role in assuring performance, quality, and safety. An employer must establish effective communication channels with contractors. Supervisors and managers need to learn how to complete effective communication with contractors to accomplish shared goals, including safety. Failure to use proper communication channels can create unnecessary liability for the company.

Special Committees and Teams Many companies have in-house fire brigades, emergency response teams, safety committees and other groups that have special responsibilities. The roles are in addition to regular job duties. Individuals on these teams or committees leave their primary jobs when the need arises. Individuals on these teams need special training. The training may include special drills and tests. The drills may involve teamwork among groups from within and outside the plant.

Contractors Contractor employees working at company facilities need training in safety as much as company employees. The contracting company should establish training requirements including safety for contractors and their employees. A contract should have clauses that cover training requirements for safety and which rules, policies, and standards apply to the contractor and its employees.

Product Users Many product users need training in safe use of products. Recall (Chapter 7) that legal principles often require warnings and instructions with products to minimize liability. Usually, manufacturers provide manuals and instructions with their products. The safety information must be clear and understandable for all potential users. There may be a need for instructions in several languages. Instructions may include warnings of various types interspersed throughout the instructional materials. For some products, a CD or other video product provided with the product may cover enhanced instructions.

For large, complex products, a manufacturer may want to provide additional training materials to help users operate and maintain the product correctly and safely. Manufacturers' field staff may provide live training. Field staff must not give wrong advice that leads to accidents and injuries. Doing so creates significant liability. See Case 7-2.

When there are changes in products or safety problems with a product, a manufacturer should try to reach users to provide updated information. Many companies have registration cards or online registration for product buyers. That provides contact information. For some products, such as automobiles, manufacturers must keep records of owners that help implement product recalls and inspection notices.

Public Some operations and products can affect people in a community surrounding a plant. Some companies provide training for the public about hazards of systems and equipment and how to prevent injury. For example, electrical utilities often provide public notices about dangers of excavating into buried lines and dangers of substations and overhead lines. Several railroads offer safety programs for schools. Local police and fire departments offer public training and informational materials about traffic and fire safety. Any operations that could create dangers for a community should offer training programs for local authorities and materials that inform the public about warning systems, hazards and means of protection.

Engineers Engineers and other professionals need training in safety because their sphere of responsibility can impact safety. A National Council of Examiners for Engineering and Surveying survey found that virtually every engineering discipline and every type of engineering job function had safety responsibilities. ABET, Inc., an organization that accredits engineering degrees, has included safety as part of engineering curriculum standards.

Training Methods

There are many training methods. The method to use depends on many factors, including subject content and delivery method. For example, there are few ways to reach the public or most product users. Sometimes producers can provide warning signs or user manuals only. Sometimes they use advertisements, notices through social media or features on radio and television shows to reach product consumers.

With captured audiences the possible methods can expand. Standard audiovisual presentations may work well. The methods may include stand-up lectures, role playing, case studies, problem solving, special training facilities, computer-assisted instruction, and other techniques. The method depends on whether one is trying to convey general knowledge or develop skills to a desired level of performance. Cost of development and delivery also affect the training method.

A common, low-cost way to reinforce training for workers is through periodic sessions with small groups. A

supervisor conducts the session with employees. Some call these sessions tailgate or toolbox safety meetings. Most sessions are about 15 minutes long. The sessions may use various techniques. Usually, a session focuses on only one or two topics to keep learning simple. A session may uses a discussion format as a way to reviews hazards, controls and safe procedures of work. A key to session success is selecting topics meaningful to the group and its work.

Contingency or Situational Training in Safety

Too often people learn how to do a job involving normal operations or conditions. The training may show someone how to use a machine or equipment item. Too often people have accidents when a situation or machine is not working normally. They do not know what to do in such circumstances. Frequently, the result is an accident and injury.

Those involved in work that is not part of normal operations, such as maintenance and cleaning of machines and equipment, must learn special safety techniques. Maintenance and cleaning may require removal of guards or testing machine performance. The workers may need to implement lockout and tagout procedures, but certain tasks require machine operation. These workers may have exposure to hazards during normal operations.

When normal operations start going wrong, people must decide how to act. When doing non-normal tasks, workers must know safety procedures. Errors can be disastrous.

These situations are examples of contingencies or special situations. Training for sports illustrate contingency or situational training. For many sports, a lot of the training addresses game situations and how to perform when they occur. A daily training schedule for five weeks during the entire preseason of a National Football League team listed different situations addressed each day. The group worked on different game situations each day. During games the players needed to respond quickly to changing game situations. They based decision-making on game situations. That is why the team spent so much time on situational drills and training.

Similarly, workers need to learn about potential work situations and how to perform safely. Training programs must teach workers about contingencies or situations, the events that are out of the ordinary. Training must explain how to act safely when the unusual occurs. Contingencies are events and conditions that are not ordinary or routine. An example is a machine that starts to produce faulty parts (see Case 31-3). A contingency occurs when something breaks, when a process overheats, when pressure gets too high, or when equipment malfunctions. There are many kinds of contingencies. Maintenance, repair, and cleaning are not production activities. These activities are forms of contingencies.

Procedures and training programs must include contingencies. Workers with limited experience especially have difficulty recognizing the symptoms of things going wrong. They often fail to recognize what is happening and why it occurs. Once they recognize that something is wrong, they need to know what actions are safe. They need the authority to act to protect themselves and others. Too often people place the importance of doing a good job above the importance of safety. Too often production or avoiding criticism of a supervisor are paramount to safety.

Training Aids

There are many training aids and materials available for safety. Several companies produce very good training materials in a wide variety of formats and media. One can find information about them in safety and health periodicals and journals. Some publications produce safety product directories that include training resources. NIOSH[2] offers many safety training materials.

Evaluation

Safety training is worthwhile only when it transfers knowledge into practice. The only way to determine if training accomplishes its goal is measuring if someone implements knowledge or skill. One can test trainees during and at the end of training sessions. If performance is essential, there should be standards that a trainee must achieve. In some cases mastering a skill at a certain level becomes the standard. There should be evaluations to determine if each student meets a standard. There may be formal tests that trainees take or informal review and discussion with trainee groups. One can also apply statistical techniques to observed behavior recorded by trained observers. One can assess accident rates, loss rates and other data, but these are trailing indicators with long delays.

For general safety knowledge, some employers have begun to use certification and certificate programs that include tests of knowledge on safety. Certification organizations offer testing before awarding a certification. The tests evaluate knowledge and skills related to general or specific safety topics.

There are also certificate programs that incorporate some form of testing at the end of training. Certificate programs are training programs with specific courses or content. They are not certifications. Participants receive a certificate of completion when they finish the program elements.

Generational Differences and Impacts on Training

Some have given various names to groups of people born at different times. They are generational groups. People in various disciplines recognize these groups and differences

among them. Businesses have learned to understand the differences and how to deal with generational groups. This section will introduce the groups, give some general characteristics and focus on why work and training approaches vary for these groups.

Baby Boomers People in this group were born following World War II in 1946–1964.This group made work a high priority compared to personal life. They are optimistic about their opportunities and open to change. They moved through civil rights expansion and protests of the Vietnam War. They are narcissistic. Some called them the "Me Generation." Many work beyond age 70 or part-time following retirement.

Generation X Individuals in this group were born between 1965 to 1980. They question authority and focus on a balance between work and life. They grew up with television. They focus on "what's in it for me." They have more education than their predecessors. They focus on stable homes and financial planning. They take on challenges.

Generation Y or Millennials Born between 1980 and 1994, this group is technology-wise. They experienced the rapid growth of the internet and its impact on society. They are the most educated generation of workers. They became exposed to many subjects through the expansion of television channels. They are diverse in many ways, are flexible and have less brand loyalty. Many grew up in dual income homes or in single parent families. Many have credit cards cosigned by a parent.

Generation Z This group forms the next generation of workers. They were born between 1995 and today. They have greater diversity than ever. They know a lot about their environment and are learning through use of technology. They have never experienced the world without the Internet.

Comparison and Impact on Training and Work Table 32-1 provides an outline of characteristic by generational group. Each group approaches aspects of work differently. Understanding the differences has some impacts on the training methods that work best for each group. However, differences do not change who needs training.

Differences in Thinking, Learning, and Communicating

People do not think alike. Their minds work in different ways. Understanding some of the differences in thinking offers some insights into effective communications and learning.

Left-Brain vs. Right Brain Some researchers classified thinking into left-brain and right-brain functions. The theory assigned different kinds of thinking primarily to each side. For example, the theory assigned language, logic, critical thinking, numbers, and reasoning to the left side of the brain. It assigned creativity, intuition, images, emotions, music, and color to the right side of the brain.

More recent research finds that different parts of the brain do have different roles. It also shows that the organization of thinking is not as simple as suggested by the left-brain, right-brain theory. Both sides of the brain work together for many thinking functions.

Other Thinking Models Others also recognized that people do not think alike. They developed instruments to assess and characterize how people think.

TABLE 32-1 Generational Workplace Characteristics[a,b,c]

Characteristic	Baby Boomers	Generation X	Generation Y
Work	Jobs and performance important, working long hours is OK	Creative use of technology, self-reliance	Goal-oriented, multitasking, frequent job changes, technology part of workplace
Leadership style	Collegial	Everyone alike, ask why	Needs more structure, involved in decision-making, outcomes
Interactive style	Team player	Entrepreneur	Participant, questions rules
Communications	In person	Direct, specific expectations	Via technology
Feedback	Desire recognition	Freedom	Meaningful work, rewards
What motivates	Money, title	Forget the rules, career development	Outcomes, accountability, clear expectations, work with creative people
Work & family life	Little balance	Resents work requests that interfere with social	Flexible work hours

[a]"Supervision of Intergenerational Dynamics," University of Iowa, School of Social Work. www.uiowa.edu/~nrcfcp/training/documents/Participant%20Packet%20Intergen%20Dynamics.pdf
[b]Hammill, Greg, "Mixing and Managing Four Geneerations of Employees," *FDU Magazine* Online, Winter/Spring 2005. www.fdu.edu/newspubs/magazine/05ws/generations.htm
[c]"Generational Differences Chart," West Midland Family Center, Shepherd, Michigan. www.wmfc.org/uploads/GenerationalDifferencesChart.pdf

For example, Ned Hermann created a 120-question instrument called the Herman Brain Dominance Instrument® (HBDI®).[3] Results create a thinking profile for individuals using four quadrants in a Whole Brain® Model. Most people have thinking in more than one quadrant. The results use colors to represent the quadrants. The quadrants are:

Blue	Logical, analytical, fact based, quantitative
Green	Organized, sequential, planned, detailed
Red	Interpersonal, feeling based, kinesthetic, emotional
Yellow	Holistic, intuitive, integrating, synthesizing

This instrument not only characterizes the dominant thinking of individuals, but can evaluate the thinking among those in a group. Once people understand the thinking of others, they can learn how to communicate more effectively with those with other kinds of dominant thinking. They can improve teamwork, leadership, problem solving and other challenges for the group[4]. For example, the following four steps touch all four quadrants of thinking:

1. Context	Let people know what is going on, the big picture, and why you are communicating.
2. Agenda	Provide an agenda or plan that sets expectations.
3. Facts & Date	Offer details that explain the context and agenda
4. Engage	Stories and interactive discussion allow people to connect to what is presented. Create two-way interactions to gain involvement

By including all four steps in a communication, the message touches people with thinking in any of the four quadrants.

Management of Training

Management of training and safety training can be a huge task for an employer. Someone must identify all the training required by law and regulation. There are other requirements for training to achieve safety in an organization. The complete list of requirements can become sizeable.

The next task is to identify which individuals in an organization need training and which positions requires specific safety knowledge and skills. Mapping training requirements to positions requires knowledge of work hazards and position responsibilities.

Someone must create a training plan. The plan establishes the subjects, materials, and delivery methods necessary to cover all requirements for all participants. Some topics apply to everyone. Others apply to certain work groups or to specific position types or crafts. The plan must include the frequency of training. Some training occurs once. Some involves refresher training. The plan must position training into a schedule. Some training may occur over an extended period and limit the number of participants during each schedule period. Other training may require taking workers from their jobs for limited work interruption. Some training may apply to everyone and have urgency to deal with a company-wide issue.

Part of training planning is setting budgets and developing or purchasing training resources. Training planning involves scheduling classrooms, training equipment, or materials. It may involve contracting for training services and instructors. Training planning may involve setting training priorities that recognize what training is most important. The priorities help manage limited funding and other resources.

Depending on the scale of all the training required, someone in charge may need staff and computer systems to manage all the details. There is a need for a capability to communicate with each employee requiring training and their supervisors or managers. Training management may need a database system to manage the many details.

Training involves tracking of delivery and evaluation of effectiveness. Suppose someone has mandated training and is absent from the scheduled training time. Someone must reschedule that training session to assure compliance. This is merely one element of training management complexity. Tracking of attendance and participation may not be as important for training covered within workgroups, such as through toolbox talks by a supervisor. The supervisor may handle any absence with individual instruction or discussion.

There is a need to track completion of a training plan. There may be completion records for each employee and for certain positions or work categories.

Someone in charge of training needs to compile feedback on some training programs. Attendees may offer suggestions on making them more effective or rate instructors. Collecting participant feedback efficiently and compiling feedback results may require staff or additional software or equipment.

The end goal is achieving safe workplaces and reducing injuries. There may be studies to link training and safety performance through leading and trailing safety indicators.

Training management is an ongoing process. New requirements continue to arise. New employees or those changing positions create new training needs.

32-4 PROMOTING SAFETY

There is a need to reinforce proper attitudes and actions. There are many approaches for promoting safety. This section addresses a few.

Posters, Flyers, and Newsletters

Posters One method for reminding people of safety concepts, policies and safe actions is through posters, flyers and

newsletters. Such publications keep important safety messages in front of people. In view of the competition for people's attention, are these publications effective?

One study[5] looked at a poster about sling safety for hoisting equipment. The poster gave a detailed instruction: "Hook that sling!" After a poster was on display six weeks, there was a 13% increase in hooked slings. Some workers could remember that the poster was up but few could remember the content.

Another study[6] looked at style of posters. The study compared a humorous poster and one with a medium threat. Researchers questioned workers to find out if they recalled either of the two posters and recognized them. The results were as follows:

Poster Type	Recall (%)	Recognition (%)
Humorous	18	15
Medium threat	11	10
Both	18	49
Neither	52	27

Workers preferred the serious poster over the humorous one. The reviewer concluded that recall and preference for style of posters have little relationship with their impact on safe behavior.

Opinions about safety poster content and use vary. One safety poster researcher uses the following criteria: be specific, be accurate, be positive, design for safe behavior, site prominently and stick to a simple message. Another suggests the following: have a clear strategy, target the content, attract attention, have a positive and attainable slogan or message, arouse interest, seek to have something readers will remember, and call for specific action.[7] The National Safety Council has developed recommendations for posters, bulletin boards and safety displays.[8]

Newsletters Newsletters, whether in print or electronic format, provide a good method for telling about events and success stories, conveying policy, and giving alerts. The stories may cover accidents and what could have prevented them. The stories may be personal accounts of how an individual or group achieved safety. Newsletters can carry information about organizational success and performance data.

Awards and Rewards

Many people feel that recognition of an individual's safe behavior is the best way to achieve desired actions. Behavior theories support the need to reward correct behavior. There are many ways to recognize people for what they do correctly. Imagination helps create new ways to provide rewards. In general, immediate reward or recognition is best. Delayed recognition is less effective. Feedback each time there is a correct behavior is desirable, but not often possible. Verbal recognition by a supervisor is one of the best and least expensive kinds of feedback.

There are many kinds of award and reward programs. Vendor companies sell awards and materials for conducting award programs. There are awards for individual behavior and for group achievements. Group programs introduce peer pressure and peer support toward correct actions. Particular programs may be effective for a limited time, but then people lose interest. Changing programs can help maintain interest. Some kinds of awards incorporate company or work group logos and names. These help develop pride and commitment to the identified group and a positive attitude and image for the group. Different kinds of awards or rewards may appeal to different generational groups.

Some organizations offer T-shirts and other clothing. In some cases the clothing increases visibility to make workers safer. When a company includes its logo, a patch or other identification on the clothing, the items can build loyalty to the employer. The clothing advertises the affiliation with an employer. The content can promote safety or highlight safety achievements.

Some companies have established training and certification as a motivational approach. Particularly work group leaders and managers must complete preparation and testing of safety knowledge for leaders. Some companies require people in positions of leadership who work for a contractor also to complete the training, testing and certification. That becomes part of the contract. The results include an increase in work group focus on safety and peer recognition for having achieved a company standard. The company recognizes their accomplishment in various ways, such as use of company cars and in-house publicity for the organizational unit or work group. In some industries, such as construction, companies can gain large rebates on insurance for a project if claims fall below the average claim rate used to set the insurance premiums.

EXERCISES

1. Work with an employee group to conduct a job safety analysis. From the results, develop a training program for each employee.
2. Review the training program for an employee group. Identify ways to improve it.
3. Design a computer database management application for tracking training requirements and training completed for each member of an employee group.
4. Research generational groups further. Craft training strategies for each group.

5. Complete an HBDI questionnaire. Plot the results on a chart of four quadrants. Repeat the procedure for one or more other people. Compare results and identify similarities and differences in thinking patterns.

REVIEW QUESTIONS

1. Explain the purpose for policies. For procedures. Explain how they are related.
2. What are general safety rules?
3. What is a standard operating procedure or SOP?
4. Give one reason why each of the following are important for procedures:
   - **(a)** keeping current
   - **(b)** standardization
   - **(c)** levels of procedures
   - **(d)** signature
5. How does one start to develop a procedure?
6. What is a special procedure? Give an example of a task requiring special procedures.
7. When someone signs a hot work permit or confined entry permit, what does the signature mean?
8. Explain briefly how each of the following are procedures:
   - **(a)** warnings
   - **(b)** instructions
   - **(c)** alarms
   - **(d)** hand signals
   - **(e)** symbols
9. List and briefly explain five principles of learning.
10. What is contingency or situational training? Why is it important for safety?
11. Identify why training is important for each of the following:
    - **(a)** new employees
    - **(b)** experienced employees
    - **(c)** supervisors and managers
    - **(d)** special committees and teams
    - **(e)** contractors
    - **(f)** product users
    - **(g)** public
    - **(h)** engineers
12. In what way are posters, flyers, newsletters, awards and rewards an element of safety training?
13. What are generational groups? How do these groups affect training methods?
14. What are characteristics of left brain and right brain thinking? How valid is this theory?
15. What is the Hermann Brain Dominance Instrument (HBDI)? What is it used for in organizations?

NOTES

1 ANSI Z 535 series, American National Standards Institute, Washington, DC. (www.ansi.org); ISO 3864 series and other ISO standards, International Standards Organization, Geneva, Switzerland. www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=52692; OSHA 1910.145, Specifications for Safety Signs www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9794

2 www.cdc.gov/niosh/

3 www.hbdi.com/uploads/100046_Brochures/100678.pdf

4 www.herrmannsolutions.com/blog/getting-your-point-across-4-steps-to-effective-virtual-communications/

5 S. Laner and R. G. Sell, "An Experiment on the Effect of Specially Designed Safety Poster," *Occupational Psychology*, 34: 153–169 (1960).

6 Reported by R.G. Sell, "What Does Safety Propaganda Do for Safety? A Review," *Applied Ergonomics*, 8: 203–214 (1977).

7 "What Makes an Effective Safety Poster?", *National Safety and Health News*, 134: 32–34 (1986).

8 *Posters, Bulletin Boards, and Safety Displays*, Data Sheet I-616-revision 86, National Safety Council, Chicago, IL, 1986.

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CHAPTER 33

ERGONOMICS

With the introduction of computers as common workplace equipment, interest in ergonomics for work activities grew significantly. In addition, some highly visible incidents uncovered the need for major design improvements that reflect the capabilities and limitations of people. The result is having ergonomics as an integral part of safety and health practice.

33-1 INTRODUCTION

Definition

Ergonomics has become a major element of safety. About one-third of all worker compensation claims involve repetitive motion disorders or cumulative trauma disorders. Some estimate that such claims will climb to one-half of all worker compensation claims.

Ergonomics is much broader than safety and health. It addresses efficient job performance and the ability of people to perform tasks. It extends beyond injuries and illnesses to comfort, convenience, preferences and choice, which are important in marketing.

Ergonomics comes from the Greek words *ergon*, meaning work, and *nomos*, meaning law. Ergonomics means the laws of work. Another definition identifies ergonomics as the relationships between people and a variety of items, including equipment, environments, facilities, vehicles, printed materials, and other informational media. Ergonomics relates human capabilities and limitations to the design of products, systems, and work environments.

In the field of ergonomics there are three major kinds of relationships, which are somewhat interrelated. The relationships are performance, safety and health, and satisfaction. Performance attempts to extend the abilities of a person by improving output and reducing errors. The safety and health relationship attempts to minimize accidents and injuries resulting from human limitations. Satisfaction involves designing things that people judge as comfortable, desirable, convenient, and pleasing.

Ergonomics occurs through design. Designers must understand human behavior, physiology, kinesiology, biomechanics, and other fields that study the characteristics of humans. Designers apply human characteristics in creating workplaces, furniture, vehicles, buildings, equipment, and informational products for human use. Designers must anticipate and understand normal operation and human behavior. In addition, designers must anticipate and understand foreseeable misuses (see Chapter 7) and non-normal tasks, such as maintenance and repair tasks. Ergonomics data contribute to designing for all of these.

Ergonomics, human factors engineering and human engineering are virtually the same. Some people may argue over subtle differences. There are some other names for this field. For example, some call ergonomics in building design architectural psychology or environmental design.

History

To a great extent, ergonomics developed out of aviation and other military matters in World War II. Critical tasks in flying an aircraft required effective presentation of information and error-free operation of controls. Those kinds of applications began to use the term human factors engineering. Today, ergonomics has become a fairly common term. Its applications continue to grow. Circa 1980, the application of ergonomics to the office environment paralleled the growth of personal computers. Circa 1985, ergonomics started to get more attention in occupational safety because claims for cumulative trauma disorders grew rapidly.

Applications in This Book

Many previous chapters discussed hazards, injuries and controls that involve ergonomics. For example, Chapter 7 discussed warnings and other chapters added information about signs. Chapter 11 discussed design of floors, stairs, ladders and handholds. Chapter 13 included a review of cumulative trauma disorders and design of tools and machines that incorporate ergonomic features. Chapter 15 covered manual materials handling and prevention of lifting injuries. Chapters 18 to 20 covered human aspects of thermal conditions, pressure and lighting. Not only is health a concern in hot and cold environments, so is performance. Altitude and high pressure environments impact human performance and impose dangers. People cannot function if lighting is inadequate. Both quantity and quality of light

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CASE 33-1

4 am, March 28, 1979, Three Mile Island, Pennsylvania. One of the nuclear power plants at this location near Harrisburg, PA, experienced a loss of coolant accident. During the first minute of the event, operators saw more than 300 display panel lights go on and off. During the second minute, the number of lights expanded to more than 800. Given the rapid growth of information, operators incorrectly diagnose the problem. For more than two hours they did not recognize there was too little cooling water. They thought there was too much. In fact, the reactor was boiling dry.

Investigations following the accident revealed many problems. They involved questionable design of the control rooms and the large number of information displays.

For example, two digital controllers sat side by side and looked exactly alike. The left one concentrated borated water and the right one diluted it. In addition, operators had to remember that the decimal point in the displayed number was one digit to the left of the last number on the left controller. The decimal point was one digit to the right of the last number on the right controller.

Two auxiliary feedwater meters provide another example of poor ergonomic design. One meter labeled A was on the left. One labeled B was on the right. There were two switches associated with the meters. The switches also had labels A and B. However, switch A was to the right of switch B.[a]

[a]B. Sheridan, "Human Error in Nuclear Power Plants," *Technology Review*, February: 23–33 (1980).

affect performance. Reduced performance and errors may lead to accidents. Chapter 23 covered noise and vibration, both of which impact performance and safety. Chapter 28 reviewed personal protective equipment, where ergonomics is an essential element in proper and comfortable fit.

This chapter will discuss other aspects of ergonomics and safety and health applications for them. Other areas include anthropometry, displays and controls, work physiology and biomechanics. The Bibliography at the end of this chapter provides additional ergonomics references. A number of organizations have excellent publications covering ergonomic considerations in specific work settings, such as offices.[1]

Ergonomics can become quite complex. Automation continues to take over many tasks. A resulting dilemma is developing manual skills for complex tasks when automated systems fail. Case 33-1 provides one illustration of the paradox. Case 33-3 offers another example for commercial aviation because the current aircraft essentially fly themselves. Pilots enter data and manage some aspects of takeoff and landing procedures. Many pilots have not developed skills to fly aircraft manually, which is what pilots did in the past. Chapter 1 mentioned another similar pilot situation.

CASE 33-2

July 1987, Washington, DC. OSHA proposed a $2.6 million penalty against IBP, a large meat packing company. OSHA charged IBP with willfully failing to record 1,038 job-related injuries and illnesses at its plant in Dakota City, Nebraska, during 1985 and 1986. The unreported cases involved knife cuts and wounds, concussions, burns, hernias, fractures and carpal tunnel syndrome.[a]

OSHA had no specific standards on ergonomics related to workplace safety. As a result, OSHA later agreed on a smaller fine for IBP because of the lack of specific ergonomic standards. In part of the settlement, OSHA required the company to do research into ergonomic aspects of its workplace.

In November 2000, OSHA issued an ergonomics standard at the end of the presidential term of President Clinton. Developing the standard had created a bitter battle between employers and unions. Employers argued that many ergonomic injuries result from other than on-the-job activities. Some employers claimed injuries are a mix of work and genetic or existing health conditions for which employers become liable. In March 2001, Congress passed Joint Resolution 6 that rescinded the OSHA ergonomics standard and the new President Bush signed the bill.

As a result, OSHA developed non-mandatory guidelines for employers, especially those in meatpacking and poultry businesses.[b] It also established that it could cite an employer for ergonomics injuries and illnesses under the General Duty Clause of the OSHAct of 1970.

[a]*Ergonomics Program Management Guidelines for Meatpacking Plants,* OSHA, 1993. www.osha.gov/Publications/OSHA3123/3123.html

[b]*Officewise: A Guide to Health & Safety in the Office*, Edition No. 5, WorkSafe Victoria, Melbourne Australia, January 2006. www.worksafe.vic.gov.au/forms-and-publications/forms-and-publications/officewise-a-guide-to-health-and-safety-in-the-office

CASE 33-3

May 31, 2009, Atlantic Ocean. Air France Flight 447 departed with 216 passengers on an 11-hour, 5,700-mile trip from Rio de Janeiro to Paris, flying overnight. During the flight, the aircraft encountered some bad weather, but disappeared into the Atlantic Ocean.

Eventually, recovery efforts located and retrieved the main parts of the aircraft and its flight recorders. During the encounter with bad weather, the aircraft's automated flight management system had failed. The system was programmed to prevent the aircraft from stalling. During a stall, an aircraft has a nose-up orientation that causes the plane to lose lift. The plane falls through the sky. Dropping the nose to a downward position will allow it to regain lift and air speed that allows it to fly.

Apparently, the pilots did not recognize the stall position of the aircraft, even when an audio stall indicator began sounding. The co-pilot actually pulled the nose upward with his manual control. Within four minutes the plane had descended from about 35,000 feet. Other factors contributed.[a]

A potential problem of balancing hands-on skills with automation was likely involved. During the prior six months, the captain had logged 346 hours of flight, During only about four of those hours was the captain in actual control of the plane.

[a]www.vanityfair.com/news/business/2014/10/air-france-flight-447-crash

Some General Principles

A few principles of ergonomics apply to a wide variety of applications.

People versus Machines People and machines have different capabilities. Each is best at some functions. Table 33-1 lists some functional differences between people and machines.

Design the Job to Fit the Person People have limitations. They do some things well and others not very well. Failure to recognize capabilities and limitations may cause people to make errors or create hazards. There are two main classes of errors. One is errors of commission, which is doing something that should not have been done. The other is errors of omission, which is failing to do something that should be done. Asking people to adjust to a job, equipment, or environment may be asking them to exceed their capabilities. In fact, the job, equipment or conditions may be harmful.

Work Smart, Not Hard One way to increase productivity is speeding up the activities and methods already in place. However, people may not be able to perform faster without increased errors or damaged product. Another way to increase productivity is finding new ways to accomplish something. That involves redesign of processes. The new ways may take advantage of technology and recognize limits of people. The new methods may reduce errors and accidents by recognizing the capabilities and limitations of humans and new capabilities of machines. Applying knowledge about causes of errors and accidents can help improve productivity by eliminating them as causes.

All People Are Not Alike There are variations among people. Some differences are easy to observe, such as size, build, weight and gender. Other differences may require measurement of physical, medical, physiological, and behavioral factors. Examples are reaction time, strength, vision, coordination, physiological responses to environmental conditions, beliefs, and other attributes of people. Some of these

TABLE 33-1 A Comparison of Functional Capabilities of People and Machines[a]

People are Better at:	Machines are Better at:
Detecting signals in high noise environments	Responding with minimum lag time (Machines have microsecond lags, whereas people have lags of 200 ms or more.)
Recognizing objects over varied conditions of perception	Precise, repetitive operations
Handling unexpected occurrences	Storing and recalling large amounts of data
Ability to reason inductively	Monitoring kinds of functions
Ability to profit from experiences	Deductive reasoning ability
Originality	Sensitivity to stimuli. (The range of human sensitivity is limited.)
Flexibility of reprogramming	Exerting force and power
Ability to perform when overloaded and to adjust to compensate for the overload	

[a] From D. Meister and G. F. Rabideau, *Human Factors Evaluation in System Development*, Wiley, New York, 1965.

attributes vary with age. Because people are not alike, designers need to provide adjustable features. Managers may need to treat people differently. For example, some workers may need increased training to develop job skills or placement in positions they can handle physically. There is no one job solution that works for everyone.

33-2 ANTHROPOMETRY

Description

Anthropometry is the science of measuring the human body. There are two classes of anthropometric data: static and functional or dynamic. Examples of static measurements are posture, standing height, sitting height, and length, breadth and depth of body segments. Examples of functional data are reach, range of motion and forces generated by hands and feet in different directions. Tables in Appendix A include basic anthropometric data.

Anthropometric data usually list values for 5th, 50th and 95th percentile males and females. For a given dimension, 95% of the population is larger than the 5th percentile value; 95% of the population is smaller than the 95th percentile dimension; 50% of the population is larger or smaller than the 50th percentile dimension.

People who are tall and at the 95th percentile in height do not necessarily have arms or legs that are at the 95th percentile. There is a moderate correlation among many dimensions of body members.

One must apply anthropometric data carefully, since reference data may not apply to the population a designer must consider. Lightly clothed or nude subjects are the source of most static data. When applying these data during design, there is often a need to make some allowance for clothing. Some of the main data are now about a generation old and may not fully reflect today's population. Data in sources found in the Bibliography are primarily from young adults in the United States and may not apply to older populations. Diffrient et al.[2] provides data for a wide range of populations. There are few data sources for children, the elderly and the disabled. Data sources may not reflect the true dimensions for populations in other countries.

There are special instruments for making anthropometric measurements. Calipers and anthropometers are instruments for measuring many static dimensions. Goniometers measure joint angles. There are standard landmarks of the body used in defining particular measurements and movements.

Application

The primary use of anthropometric data is for fit and reach. However, there are other uses. People come in a variety of sizes and shapes. A few principles apply to the use of anthropometric data in design, although each principle may not work for every situation.

1. *Design so things are adjustable for different users.* One size does not fit all. Office furniture manufacturers now provide many adjustable features in chairs, work surface heights and positioning of keyboards and monitors. Some seating and workstation equipment in factories and shops now offer adjustments. Barber and beauty chairs have had adjustment in height, tilt and rotation for years to make hair cutting and styling easier. For pallet loading there are adjustable height pallet platforms. They allow users to adjust the pallet height as the pallet becomes filled or emptied.

   People may need adjustments to read or observe an object. One example is rear view mirrors on automobiles that adjust for different drivers and sitting postures. Displays on equipment may need adjustment so a process or machine operator can easily view them. Most computer monitors now include adjustable bases.
2. *Design for the 95th percentile male to fit and the 5th percentile female to reach.* Not all equipment can be adjustable. Designs for doorways, seating in airplanes or headroom in an automobile allow only one possible solution. The design goal is to allow most people to fit within the dimensions. If a very large person will fit, a small person will fit as well. If a person must reach a control or a part, the distance from the person to the object should not be longer than a short person's reach. A tall person can reach that far, as well. Note that when applying this principle, 95th percentile data will not accommodate at least one of every twenty people. As a result, some designs may need to extend the limits for the extreme population.
3. *Know the population for a design.* If there are data for a particular population, a designer can use them. If data are not available for a particular population, a designer must rely on anthropometric data from reference tables. Those data are sources for estimating dimensions and movements of people. Some adjustments may be necessary.

33-3 INFORMATION AND DISPLAYS

The People-Machine Interface

Displays and controls are elements that form interfaces between people and machines. Figure 33-1 illustrates the interface and elements involved for people and for machines. In most cases, machines perform some functions and people control their operations. An operator must know what the machine is doing to know how to adjust its functions. *Displays* provide information about the machine to an

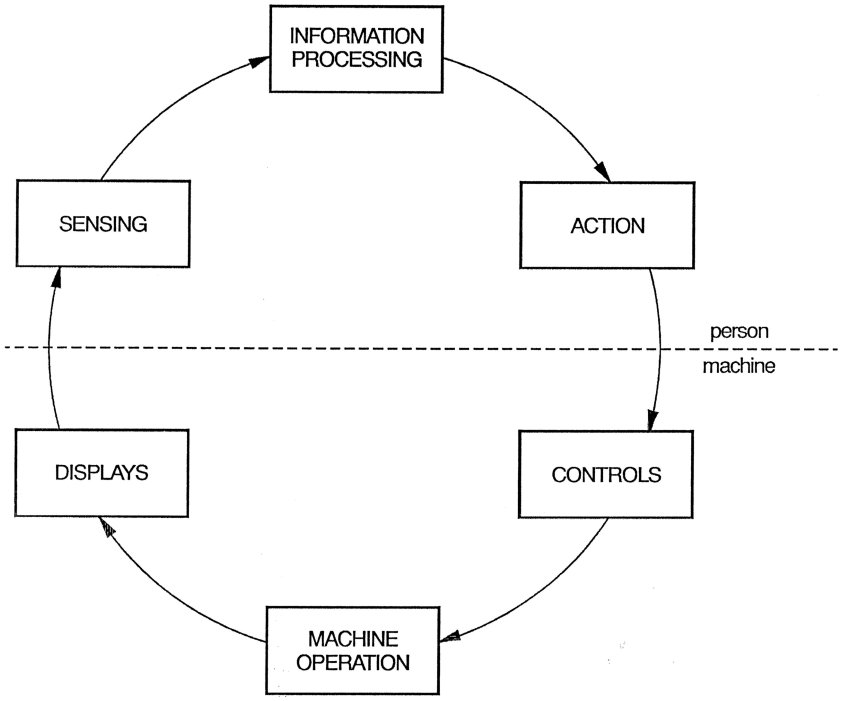


Figure 33-1. Schematic of the interface between people and machines.

operator. An operator must *sense* the information provided by the display. An operator *processes* the information, *decides* what action to take, *acts* through some control and affects the machine *operation*. If there is a failure in the person-machine loop, it may affect the performance of the system. Errors define most failures on the person side of the interface.

Sensory Reception of Information For a display to be useful, information must be in a form that an operator can sense. If it is outside human sensory capabilities, the display is useless. For example, humans cannot see wavelengths in the infrared or ultraviolet region. Few can hear frequencies near or above 20,000 Hz.

By far, vision is the richest sensory mode because it has a high rate of reception. People can discriminate among many shades, shapes, and textures.

The second best sense is audition. However, hearing is well below vision in capacity. The rate of information flow is quite limited. People can learn to discriminate among many different sounds.

The tactile sense handles less information than audition. Humans can discriminate accurately among limited shapes and textures through touch.

Processing of Information Operators who receive information through the senses need to interpret and process the information. For example, someone must convert letters of the alphabet or symbols into some meaning. A recipient must recall what the sound of an alarm means. Processing of information in the brain involves understanding the meaning of the stimuli. In addition, the brain uses long-term and short-term memory, problem solving, making judgments and deciding. Not only would the sound of 500 alarms in a nuclear power plant control room create sensory overload, it would produce processing overload. When there are multiple elements of information coming in at the same time, one must prioritize them and select which is the most important.

There are many potential sources of error as people process information. Someone may have difficulty selecting and understanding competing information. One may have to integrate information from several sources to recognize a pattern for an event that is starting to occur.

Also, one must remember what certain information means. An example is what to do in an emergency when there is an audio alarm. Assume an alarm may handle both fire and tornado signals. Building occupants may take the wrong action for one of the signals. That could be fatal. The correct action for fire is to get out of the building. The correct action for a tornado is to stay inside and take cover.

Another processing error is difficulty solving a problem, such as diagnosing what is wrong with a machine. As something begins to go wrong, an operator may not have the experience (previous information) for comparison to normal operations and know what action to take. A wrong decision or judgment may be dangerous.

Types of Displays

The sensory mode of information provides a way to classify displays. Visual displays are most common, followed by auditory displays and, occasionally, displays for other senses. No matter what sensory mode a display uses, the conditions must allow for effective information transfer. For visual displays there must be sufficient quantity and quality of light to see the displayed information. Auditory signals must be loud enough for an individual to hear. The sound should not compete with other sounds. Surrounding sound should not drown out the display sound. Cell phones can use vibration mode (tactile) as an alternate to audible ring tones.

Visual Displays

There are quantitative and qualitative visual displays. Quantitative displays present numerical values. Qualitative displays present conditions. There are also status displays, signals, lights and representational displays. Several types of displays may be integrated into a complex display.

For quantitative displays, three common styles of indicators are direct reading or digital, moving pointer-fixed scale, and fixed pointer-moving scale. Figure 33-2 gives examples of these displays and Table 33-2 summarizes the utility of each type of indicator.

Status indicators give qualitative information about the status of a system or component. Red-yellow-green traffic lights are a common status indicator that tells which lanes of traffic can move and which must stop.

There are many applications for steady or flashing signal lights. They give location, attract attention, indicate status or give instructions. Size, duration of signal, brightness, flash rate, position among other lights, and color all affect their performance in the person-machine interface.

Representational displays are pictorial or symbolic displays. Examples are video images, graphs and maps. These displays may be static or dynamic. Size of display, size of elements displayed, realism, resolution, color, and rate of change affect performance. Symbols are a form of representational display. Chapter 32 discussed them.

Display Characters and Elements

Many visual displays have numerical and alphabetical characters. The readability of characters is important, particularly when there are emergency and adverse conditions. Also important are dial pointers and scale markings. Many factors affect the ability to read displays. Size of characters, aspect ratio, font, stroke width, character color, background color and coding all contribute to reading speed and error rates.

Most ergonomics sources assume the standard viewing distance for displays as 28 in. from the display to the eyes. The sources give recommended dimensions for characters and display elements based on that distance. For other

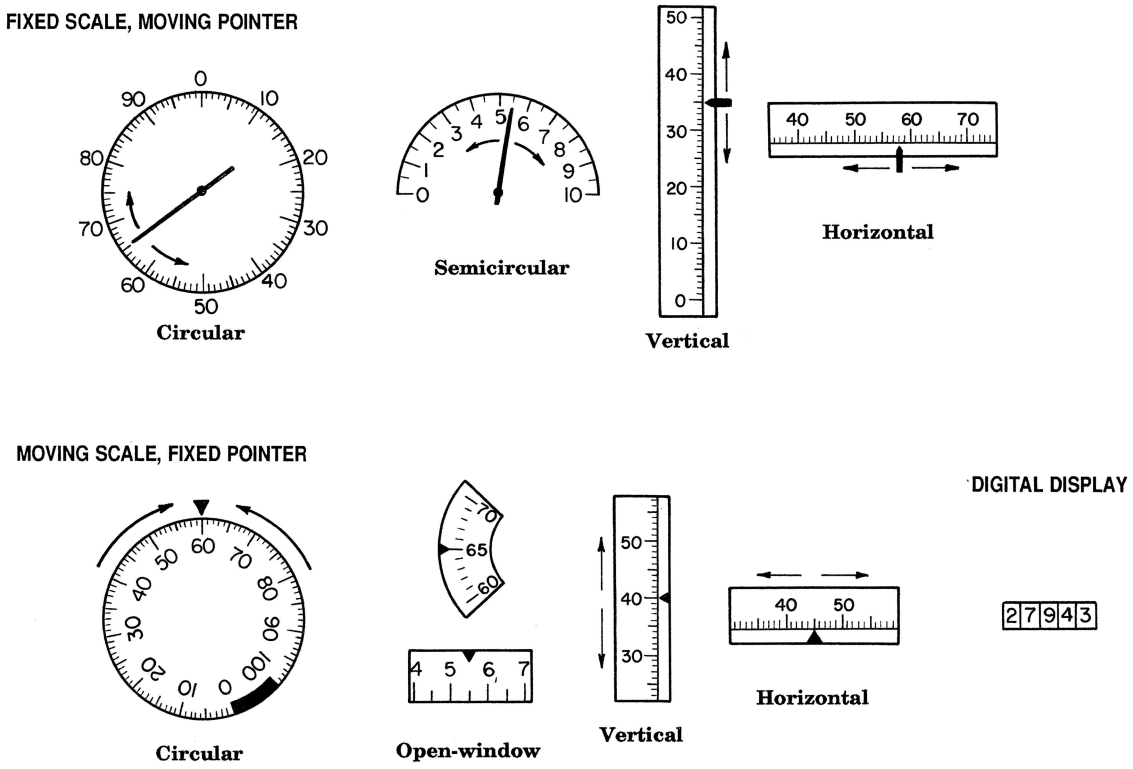


Figure 33-2. Examples of indicators for visual displays.

TABLE 33-2 A Comparison of Different Indicator Styles[a]

Used for	Counter or Digital Display	Moving Pointer -Fixed Scale	Fixed Pointer-Moving Scale
Quantitative	GOOD. Requires minimum reading time with minimum reading error	FAIR	
Qualitative	POOR. Position changes not easily detected	GOOD. Location of pointer and change in position easily detected	POOR. Difficult to judge direction and magnitude of pointer deviation
Setting	GOOD. Most accurate method of monitoring numerical settings, but relation between pointer motion and motion of setting knob is less direct	GOOD. Has simple and direct relation between pointer motion and motion of setting knob, and pointer-position change aids monitoring	FAIR. Has somewhat ambiguous relation between pointer motion and motion of setting knob
Tracking	POOR. Not readily monitored, and has ambiguous relationship to manual-control motion	GOOD. Pointer position is readily monitored and controlled, provides simple relationship to manual-control motion, and provides some information about rate	FAIR. Not readily monitored and has somewhat ambiguous relationship to manual-control motion
Orientation	POOR	GOOD. Generally moving pointer should represent vehicle or moving component of system	GOOD. Generally moving scale should represent outside world or other stable frame of reference
General	FAIR. Most economical in use of space and illuminated area. Scale length limited only by number of counter drums. Difficult to illuminate properly	GOOD. But requires greatest exposed and illuminated area on panel. Scale length is limited.	FAIR. Offers savings in panel space because only small sections of scale need be exposed and illuminated. Long scale is possible

[a] From H. P. Van Cott and R. G. Kinkade, eds., *Human Engineering Guide to Equipment Design*, rev. ed., Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 1972.

distances, characters and elements must have size adjustments. One formula for sizing the height, H, of letters is

$$H = 0.0022\mathrm{D} + K_1 + K_2 \qquad (33\text{-}1)$$

where

H is in inches

D is viewing distance in inches

K_1 is a correction factor for illumination and viewing conditions

K_2 is a correction factor for importance

Values for K_1 are as follows:

	Illumination Level	
Reading Conditions	>1.0 fc	<1.0 fc
Favorable	0.06	0.16
Unfavorable	0.16	0.26

K_2 is 0.075 for important items such as emergency labels and 0.0 for all other conditions.

Another estimate of letter height is

$$H = 0.0046D \qquad (33\text{-}2)$$

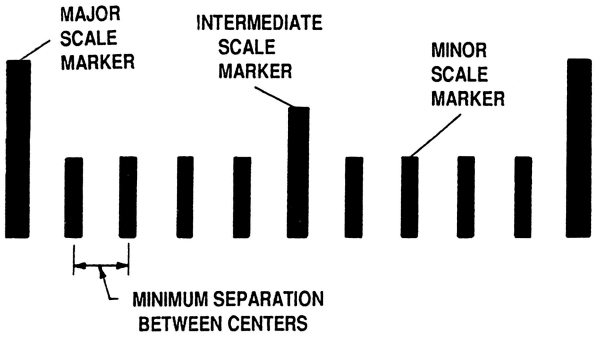
Equation (33-2) does not consider adverse conditions, importance of labels or vision problems of readers. In some cases it would be better to adjust sizes upward than to limit them to the values derived from these empirical equations. Upward adjustments become important if a designer anticipates poor lighting, information critical to safety and potential vision problems within a population of readers.

If characters have long ascenders and descenders, the size of the main body of the characters is the important dimension. Ascenders are the portion of characters that extend above the main body of letters in a font. An example is a lower case "h". Descenders extend below the main body of letters in a font. An example is a lower case "p". These descriptions mainly apply to lower case letters. Fonts with ascenders and descenders usually are easier to read compared to fonts that have letters all the same height (such as all capital letters). Adjustments in overall height can also keep readability high.

Sizing and spacing of scale markings on displays help determine reading accuracy. Figure 33-3 illustrates recommended dimensions for scale markings and spacing for a 28 in. reading distance. The dimensions require adjustments for other reading distances.

Coding

Codes are representations that have meaning. For example, the inverted triangle shape for traffic signs infers caution. Only stop signs have a hexagonal shape. One can use numbers, letters, shapes, colors and configurations to code visual information. Compound codes use two or more codes at the same time. Convenience and practical reasons usually form the reasons for use of codes. Codes require careful use. Many codes slow processing and interpretation. A person



ATTRIBUTE	LOW ILLUMINATION, 0.03 TO 1.0 ft-L	NORMAL VIEWING CONDITIONS, above 1.0 ft-L
Major scale marker height	0.22	0.22
Major scale marker width	0.035	0.0125
Intermediate scale marker height	0.16	0.16
Intermediate scale marker width	0.030	0.0125
Minor scale marker height	0.10	0.09
Minor scale marker width	0.025	0.0125
Minimum separation between scale marker centers *	0.07	0.035
Minimum distance between major scale marker centers	0.5	0.5

Figure 33-3. Recommended minimum scale marking dimensions (inches). The data assume a 28 in. reading distance and high contrast between graduation marks and a dial. In the table, the superscript asterisk demotes that the distance should never be less than one stroke width for black marks on a white dial face.

must recall the meaning of the code. However, in some cases, codes may speed up a task.

Auditory Displays

Most uses of auditory displays involve warnings and alarms. Table 33-3 lists situations in which auditory displays are preferable to visual displays. Table 33-4 summarizes characteristics of various audio alarms. With electronic technologies today, auditory displays may use spoken words rather than sounds. That avoids use of auditory codes and provides precise instructions. A possible system error is giving the wrong information for a situation.

TABLE 33-3 When to Use Auditory and Visual Displays[a]

Use Auditory Presentation If:	Use Visual Presentation If:
The message is simple	The message is complex
The message is short	The message is long
The message will not be referred to later	The message will be referred to later
The message deals with events in time	The message deals with location in space
The message calls for immediate action	The message does not call for immediate action
The visual system of the person is overburdened	The auditory system of the person is overburdened
The receiving location is too bright or dark-adaptation integrity is necessary	The receiving location is too noisy
The person's job requires moving about continuously	The person's job allows remaining in one position

[a] H. P. Van Cott and R. G. Kinkade, eds., *Human Engineering Guide to Equipment Design*, rev. ed., Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 1972.

TABLE 33-4 Characteristics and Features of Selected Audio Alarms[a]

Alarm	Intensity	Frequency	Attention-Getting Ability	Noise Penetration Ability
Foghorn	Very high	Very low	Good	Poor in low-frequency noise
Horn	High	Low to high	Good	Good
Whistle	High	Low to high	Good if intermittent	Good if frequency is properly chosen
Siren	High	Low to high	Very good if pitch rises and falls	Very good with rising and falling frequency
Bell	Medium	Medium to high	Good	Good in low-frequency noise
Buzzer	Low to medium	Low to medium	Good	Fair if spectrum is suited to background noise
Chimes and gong	Low to medium	Low to medium	Fair	Fair if spectrum is suited to background noise
Oscillator	Low to high	Medium to high	Good if intermittent	Good if frequency is properly chosen

[a] H. P. Van Cott and R. G. Kinkade, eds., *Human Engineering Guide to Equipment Design*, rev. ed., Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 1972.

33-4 CONTROLS AND MOTOR ACTIVITY

Description

After processing information in the person-machine loop in Figure 33-1, an operator activates some control that modifies what the machine is doing. Most controls require some force to activate them. Controls must have easy access. They must function within human limits of force, skill, and duration. They must operate consistent with expected system responses. They must have dimensions that fit people. If designs do not meet these and other characteristics, people will make errors when using controls or be unable to operate them.

Compatibility

Compatibility deals with the stimuli and responses that are consistent with human expectations. Compatibility may involve spatial, movement or conceptual relationships between stimuli and responses. For example, if a system component moves up and down, a control for that movement should move up and down (movement relationship). Cases 33-1 and 33-3 are examples of designs leading to errors because of compatibility issues.

The switches that controlled feedwater in Case 33-1 illustrated spatial compatibility. The feedwater displays and controls should have the same spatial relationships, left and right.

Assume that water flows through five pumps in sequence. The controls for the pumps should have the same

CASE 33-4 (See also Case 7-2.)

1980, Southern Illinois. Two workers were setting up a machine that made sand molds for castings. Vibrations would cause sand in molds to collapse, leading to defective castings. Guide pins allowed the upper and lower parts to move together and apart smoothly. During setup, the only way to detect the vibrations was by feeling. The setup used fine adjustments to remove the vibrations. One of the workers would place his thumbs on the edge of the die plates that formed the voids in the sand molds. The dies were fixed and the moving part of the machine was the table. The hands of the first worker were not available to operate the controls. He gave the second worker instructions when he was ready to move the table and test for vibrations.

The control panel was at the right side of the machine. The control for the up and down table movement was a rotary knob. The label for the control read up when the control turned counterclockwise and down when the control turned clockwise. The first worker said: "Drop the table." The second worker turned the control knob counterclockwise and the table moved up, crushing both of the first worker's thumbs.

A compatibility between control rotation and table movement up and down was at issue. With the rotary knob on the right of the machine, most people would turn the knob counterclockwise to cause the table to move down and clockwise to move it up.

Another identical machine had controls at the left. The rotary knob on the machine read the same as the one on the other machine. A clockwise rotation would mean the table moves down for most people. Counterclockwise would mean the table moves up. On this second machine, the rotation of the control knob was more compatible with the expected up-and-down movement of the table.

A different kind of control would have implemented a consistent compatibility relationship. An up and down toggle switch with a neutral position in between likely would have prevented the second operator's error. Both the control and table motions would have been the same. Moving the toggle up would move the table up. Moving the toggle down would move the table down. Location of the control on either side of the machine would not have changed the compatibility.

sequence by position as the flow through the pumps. This is an example of both spatial and conceptual compatibility.

People learn most compatibility relationships. Traffic stop lights in which red means stop or danger and green means go or safe is an example of conceptual compatibility that people learn. Some compatibility relationships are specific to particular cultures.

Compatibility relationships involving control movement are *population stereotypes*. For example, turning a steering wheel clockwise infers that the vehicle will turn right.

Compatibility relationships are tendencies, not universal behaviors. There are always some people who will not follow the relationship. Some compatibility relationships are strong and most people will follow them. Others are not as strong and behavior is less consistent within a population of people. Some design situations may involve more than one compatibility relationship. A solution may require violating one of the relationships. Use of labels will help those who may not follow the majority in applying a compatibility relationship when operating a control.

Table 33-5 lists several compatibility relationships.

TABLE 33-5 Compatibility Relationships

Control or Control Movement	Expected System Response
Spatial	
Cooking stove: Control-burner units	
Which control on front operates which burner on surface	Left/right controls operate left/right burners. Front/rear relationships confusing
Aircraft engines:	
Four controls, one for each engine should be spatially consistent with engine locations	
Operating engine control on far right	Engine at far right affected
Operating engine control on far left	Engine at far left affected
Location of separate controls for forward movement and backward movement, assuming operator is facing forward	
Operating movement control farthest forward of operator	Affects forward movement
Operating movement control nearest to operator	Affects rearward movement
Movement	
Turning a horizontal steering wheel clockwise	Vehicle turns right
Turning a horizontal steering wheel counterclockwise	Vehicle turns left
Turning a vertical steering wheel clockwise	Vehicle turns right
Turning a vertical steering wheel counterclockwise	Vehicle turns left
Moving a horizontally mounted control lever up	Controlled object moves up
For fixed-scale display and rotary control	
Clockwise rotation of control	Pointer moves clockwise. Value represented increases
Counterclockwise rotation of control	Pointer moves counterclockwise. Value represented decreases
Rotary controls and linear controls in the same plane	
Control on left, vertical scale on right:	
Clockwise rotation of control knob	Pointer moves down and value decreases
Counterclockwise rotation of control knob	Pointer moves up and value increases
Control on right, vertical scale on left:	
Clockwise rotation of control knob	Pointer moves up and value increases
Counterclockwise rotation of control knob	Pointer moves down and value decreases
Rotary controls and display movement in different planes (These may be associated with the similar action of screws and bolts)	
Clockwise rotation of the control	Movement away from control
Counterclockwise rotation of the control	Movement toward the control
Conceptual	
Red, yellow and green traffic or signal lights or signal lights	Red means stop or dangerous Yellow means caution Green means go or safe

Tracking Tasks

Tracking tasks require continuous control. The right amount of movement at the right time is critical. Many kinds of tracking tasks require the operator to keep a system on course. An example is driving a car on a winding road.

In other tracking tasks the operator sees a target on a fixed display and must keep the controlled object on the target. The display may show a vehicle deviating from the target. It is the operator's task to keep the vehicle in the center of the display or within certain bounds.

Two kinds of tracking displays are pursuit and compensatory displays. In pursuit tracking, both the target and a controlled element move. The operator tries to keep the controlled element on the moving target. The deviation between them is the error in completing the task.

In compensatory displays, either the controlled element or the target is fixed. The remaining element moves in response to a control. Again, the operator tries to keep the two superimposed. The display may present the deviation between target and controlled object as a planar representation or a spatial one. The cursor appearing on a monitor for a computer mouse is an example of a compensatory display.

Control order in tracking tasks is important. Order applies to the way the device or system responds to a movement of the control. In one display, the movement of the display may be small in comparison to the movement of the control. This is low order tracking. In another display, a small control movement may produce a large display movement. This is higher order tracking. Table 33-6 characterizes the terminology and functions of control order.

The movement of a control can be continuous, discrete (step changes), or proportional (ramp change). The displayed response varies with the design of a system or device. Higher-order tracking is very difficult for people to master because a control movement may have too great an effect on the target. Predictor displays and aiding and quickening features in controls help operators manage higher-order control tasks.

Types of Controls

There are classes of control devices. There are discrete or continuous and linear or rotary. Discrete controls have predetermined positions and transmit discrete information. They can be in one position at a time only. Conversely, a continuous control can take any position within its range and can transmit values throughout its range of movement. Linear controls essentially move in a line, whereas rotary controls move in a circle or arc. Figure 33-4 illustrates controls for each pair of classifications.

There are many factors that affect the selection and design of controls. Included are control/display (C/D) ratio, direction-of-movement relationships, control resistance, grip, control coding, control function, the control or tracking task, information needs of the operator, space availability and consequences of inadvertent activation. A brief review of some of these factors follows. For further details on control design, refer to more complete discussions in works cited in the Bibliography.

Control/Display Ratio

Control/display (C/D) ratio or control/response (C/R) applies to continuous controls. They refer to the distance a control moves relative to the movement of the display or system. They can also refer to the response of a system. C/D ratio is important in the ability of an operator to track movement. It is also important for the time required to move the control and gain the desired response of the system. The significant factors in C/D ratio vary somewhat with control order. An example of C/D ratio is the difference in steering ratio for a race car compared to a luxury car. A race driver moves the steering wheel a small amount to cause the vehicle to turn sharply. A driver of a luxury car moves the steering wheel much farther to achieve the same turning result. A race driver would have difficulty negotiating curves at high speeds without the proper C/D ratio.

TABLE 33-6 Control Order for Tracking Tasks

Order	Control Type	Movement of Device Resulting From Movement of Control	Example
Zero	Position control	Movement of device is directly proportional to control movement	Pointing a spotlight at a moving performer
First	Rate control	Rate of change in a device is related to movement of control	Depressing the gas pedal of a car changes the speed (rate of change in position)
Second	Acceleration control	Movement of the control causes a change in the rate of movement of the device	A steering wheel in a car causes the car to change direction proportional to to the angle of the front wheels
Third or greater	Higher-order control	Movement of the control causes a change in the rate of change in the device or higher-order movement	Some ship steering systems approximate a third-order control

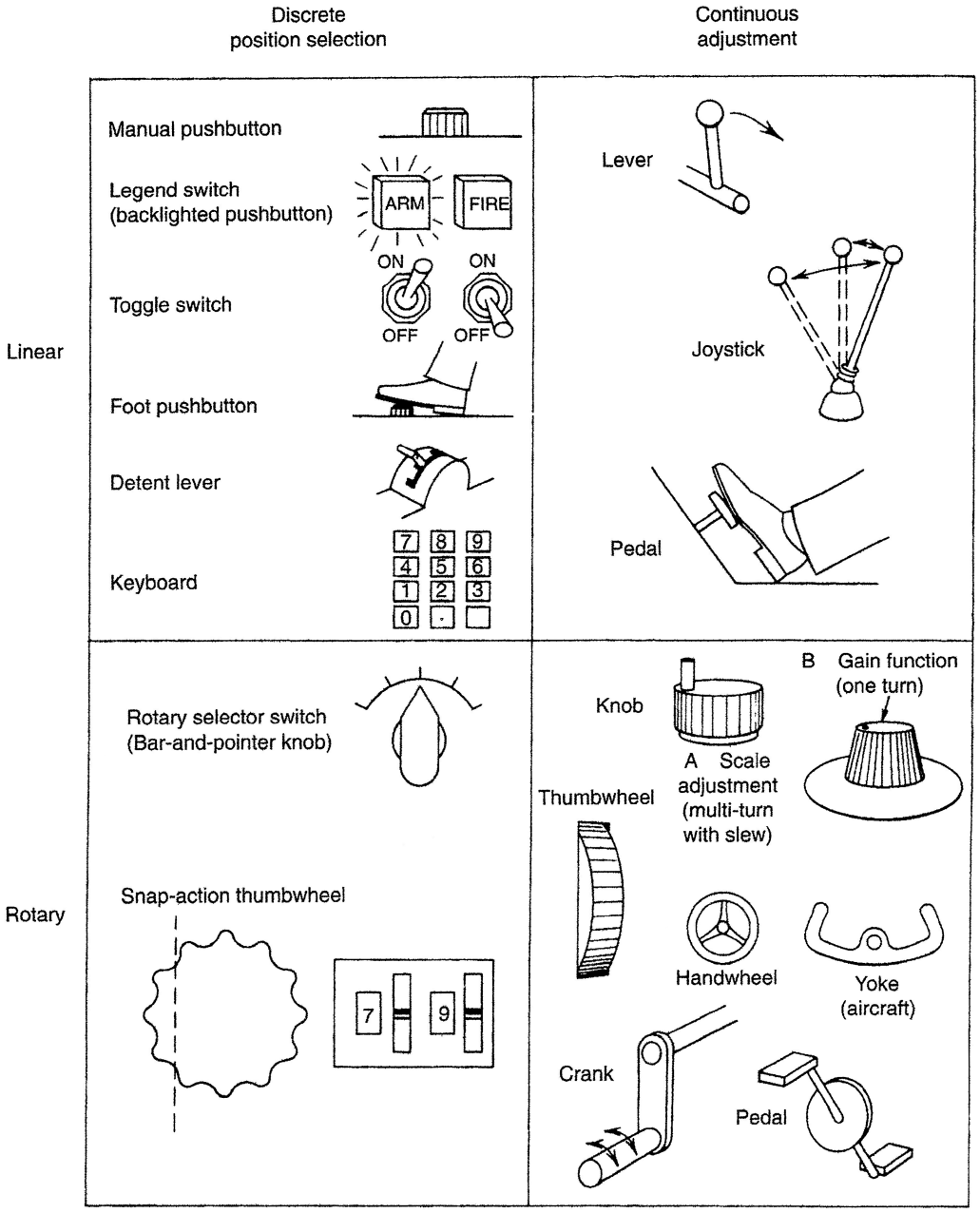


Figure 33-4. Examples of controls. (Reprinted with permission from R. Dale Huchingson, *New Horizons for Human Factors in Design*, McGraw-Hill book Company, New York, 1981.)

For many continuous controls the operator moves the display quickly to the approximate desired location (slewing movement) and then uses small movements to adjust the display precisely. This minimizes the time required to get the display on target. C/D ratio affects these two movements. A high C/D ratio increases the time required to move the display on target. A low C/D ratio may cause the operator to overshoot the target and have control problems.

Control Movement

Other factors besides C/D ratio affect response time and errors. Response times increase when an operator must move his hand a large distance to reach a control. In part the response times are a function of the muscle groups needed to reach a control. For movements less than 3 in., vertical movement of the hand is fastest. For larger movements, horizontal movements are faster than vertical.

Fore-and-aft movements have preference over lateral movements.

The amount of movement can also impact error rates. If controls have too little movement, operators may actuate them inadvertently. Compatibility of movement, standardization, and other factors are also important and affect movement time and errors.

Control Resistance

The force required to move a control affects the response time, errors, accidental activation, and operator fatigue. There are different methods for introducing reactive force into a control. Methods include use of springs, friction, viscous damping, and inertia. If forces are too low, an operator may not sense the movement and may increase errors. If forces are too high, they can reduce response times and may cause fatigue in muscles used to operate a control. That may lead to fatigue errors.

Forces and the variation of force with movement can affect performance. The resistance of a spring or elastic band increases with the distance moved. For spring resistance controls, a control positioned near the neutral point of a continuous control movement may feel "sloppy" and imprecise. Near the center of movement there is little or no resistance. To reduce this feel, designers may use a combination of elastic and inertial forces.

Some rotary controls have detents for on and off positions. If a control continues past "on" to operate a system, a high detent force to turn the control on may cause a large initial movement. The result is overshooting the desired position.

Coding of Controls

Some controls use codes to help an operator identify them. Common types of coding are location, labels, color, shape, and size. Several kinds of coding may apply to a particular control. For example, emergency shutoff push-button controls are often located away from other controls, larger than other controls, red in color, and labeled in large letters for easy identification and use. If an operator becomes trapped, an emergency shutoff control must be within reach. Controls for lowering or raising a landing gear in aircraft have had a wheel shape for a long time. A pilot can tell if his hand grasps the correct control without looking.

In selecting coding, it is important to apply existing standards, evaluate compatibility with users and consider other principles for controls.

Preventing Accidental Activation

Accidental activation of some controls can lead to serious consequences. There are several methods for protecting controls from accidental activation include recessing, location, orientation, covering, locking, operational sequences, and resistance. A desirable design may include a combination of methods. The application and potential consequences of accidental activation will affect the methods selected and used. If accidental activation leaves a system in a safe condition, rigorous protective methods are not as important. If accidental activation can produce a serious accident or injury, prevention of accidental activation is critical.

Maintenance of protection for controls is also an important consideration. A failure in a protective device may increase the likelihood of accidental activation. It must undergo repair or replacement quickly to retain the value of the protective device. Protective methods should not violate other design principles directed at minimizing errors. Figure 33-5 illustrates several of these methods.

Coding Coding methods for controls attempt to reduce and eliminate identification errors. Coding may help prevent accidental activation. Coding will have little effect on accidentally bumping a control or on population stereotypes

CASE 33-5

2014, Detroit, MI. General Motors issued recalls for more than eight million cars, SUVs, and light trucks. At least 31 crashes and 13 deaths were linked to the failure of the keyed ignition switch. The recall occurred in increments while GM reported to Congress on the matter.

The problem stemmed from a faulty ignition switch that did not have enough spring pressure on the detent plunger. A slightly longer spring with more force could have fixed the problem.

The history of the defect began more than 10 years prior to the recall. Pre-production testing of one car model in 2001 uncovered the problem. In 2005, a GM engineer recommended a redesign for the key switch. The company rejected the redesign along with a proposal to fix the problem, claiming the solutions were too costly. During 2005 and 2006, GM had more than $4 billion in financial losses and filed for Chapter 11 bankruptcy in 2009. The National Highway Traffic Safety Administration, other federal agencies, and Congress pressed GM for answers and recalls. The conflict continued into 2015.[a]

[a]www.npr.org/2014/03/31/297158876/timeline-a-history-of-gms-ignition-switch-defect

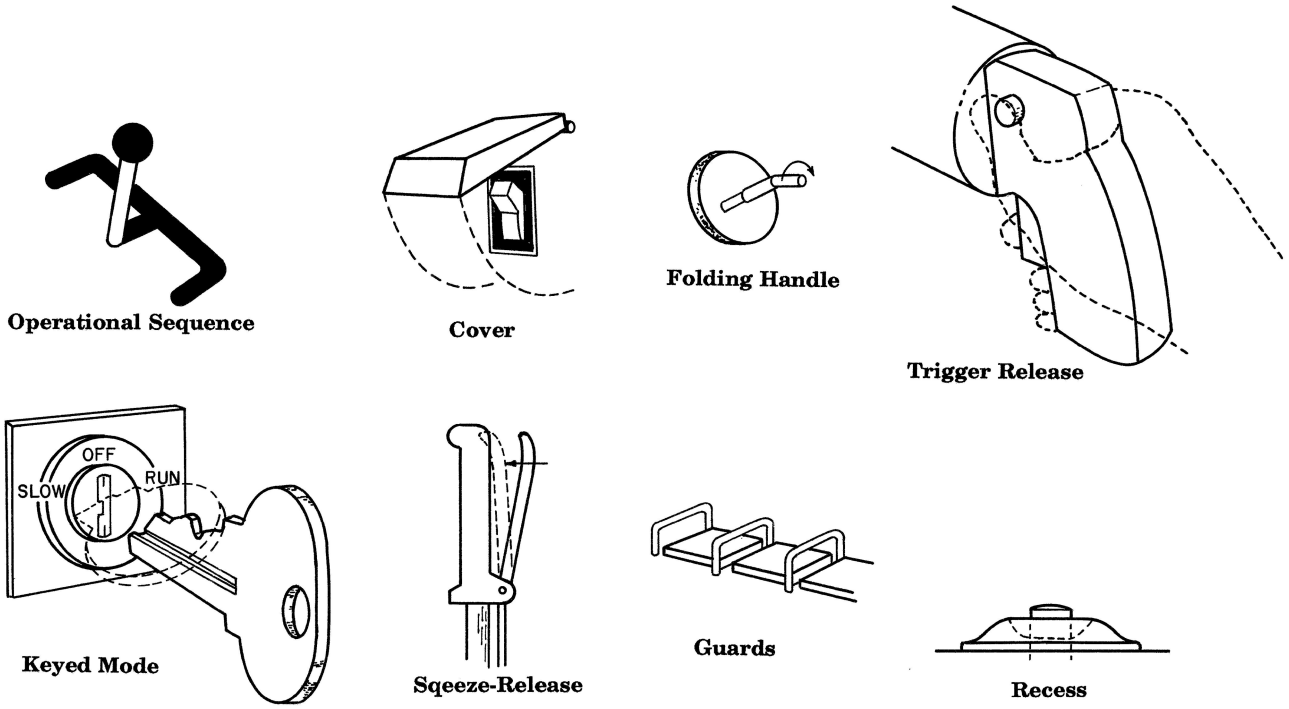


Figure 33-5. Examples of methods for preventing accidental activation of controls.

when they are inconsistent with codes. For example, people will often operate a control consistent with expectations, rather than consistent with coding or labeling.

Recessing To prevent activation of a push-button or toggle control, the button should be below the surface of the control panel. The depressed area for the button must be large enough for fingers or activating tools to access the control. If an operator wears gloves, a design should size the recessed area for a gloved finger.

Guards Another technique to prevent accidental activation is placing raised barriers or guards between push buttons or around them. These are perimeter guards. When buttons are adjacent to each other, the perimeter guards prevent activation of two buttons with the same finger. If there is a guard around a push button, an operator is likely to bump the guard accidentally instead of the button. To push the button, an operator must apply an activating force inside the guarded space. Guards require additional space between controls to accommodate them.

Another type of control guard is a cover over a switch, knob, or button. Covers may be full or partial. A full cover totally encloses the control. An operator must move the cover or a portion of it to access the control. Full or partial covers are common for foot controls when there is a danger of some object falling on the control and activating it. For frequently used controls, covers may introduce inconvenience and cause someone to remove them. Designs other than covers may be better.

Location and Space Locate controls away from other controls and away from movement of people or equipment to prevent inadvertent contact. There should be sufficient space between controls for hand, finger, or tools to operate controls without affecting others. The clearances needed will vary with the type of control.

Resistance Another means to prevent inadvertent operation of a control is to introduce a resistance force for fixed positions. Detent wheels and detent on-off rotary switches are examples of resistant forces. Some levers require a breakout force to move them from a neutral position.

Orientation One can position controls so that normal movement around them will not activate them. If hand movements are lateral, vertical control movement for toggle switches will reduce accidental activation. If one can walk by and snag clothing on a control, vertical orientation may provide some protection. If falling objects can activate a control, both horizontal and vertical orientation may be ineffective protection.

Locking There are several ways to lock controls into position. One form of lock is a position slot where the control requires two directions of movement to change positions. Today, most transmission control levers on cars require a two-position move to go from neutral to reverse and from reverse to forward.

Another form of lock is a squeeze release on a lever. This requires the operator to squeeze the handle and unlock the lever's position before moving the lever.

A third form of lock is a button on a finger control that an operator must depress to release the movement of the finger control. Many power tools use this form of lock to prevent inadvertent activation of the tool.

A fourth kind of locking control is a keyed control. An operator inserts a key into the control and turns the key to a desired position to operate a machine. Similarly, the key must return to a neutral or off position to shut off the machine.

Operational Sequence Operational sequence involves requiring multiple steps to activate the control. Some of the locking devices have operational sequence. The squeeze release lever and the push button that releases a finger control are both examples. Operational sequences may have interlocks to the next or later steps. Opening a combination padlock is a type of operational sequence. A lock pin through a hole in a hitch pin for a trailer requires an operational sequence to release the pin.

33-5 WORK PHYSIOLOGY

Description

Another area of ergonomics involves the ability of people to perform physical work. Ergonomics considers human physiological factors that limit physical work and related activities. People have limits to the amount and rate of physical work produced. There are many physiological factors that contribute to those limits. Physiological limitations may affect the ability to do physical work.

The limits may be local or general. An example of a local limit is a finger or hand that becomes fatigued from operating a hand tool or push button. The fatigue results in declining rate of activity and force generated. The repeated activity may produce pain. The fatigue may involve limitations in muscle strength or circulation supplying blood to tissues. Fatigue may link to nerve conduction limits and diseases of joints or other tissue.

The body must deliver oxygen and food to tissues or the tissues cannot function. The digestive system of the body converts food into useable forms. The body stores some excess food as body fat. The circulatory system moves the food to tissues and cells. The respiratory system transfers oxygen from the air into the blood for transport to the cells.

All these systems in the body have limits. There are limits to the food supply and the rate the body can convert it into useable energy. There are limits to the capabilities of the respiratory system and the circulatory system. For example, earlier discussions in Chapter 16 noted how carbon monoxide can reduce oxygen transport. Disease, behavior, and environment may limit the normal capacity further. Another notable example is reduced nerve conduction when potassium levels in the body decline. Reduced nerve conduction affects muscle strength and contraction.

This section will not address all of the factors that affect human physical performance. Discussion will address two important factors: energy expenditure and metabolism. Readers should refer to references on work physiology for details of other factors affecting work.

Metabolism and Energy Expenditure

Oxygen consumption during an activity affects the energy output from muscle activity. The body burns fuel through two mechanisms. The first is oxidation of fuels: glucose (carbohydrates), proteins or lipids (fats). The second involves breaking down glucose and glycogen molecules into two or more fragments, which become oxidized by other fragments. The first mechanism is aerobic oxidation. The second is anaerobic.

The rate of oxygen uptake in the body increases with exercise and decreases with rest. Figure 33-6 illustrates the oxygen uptake following a change in activity level. It takes the body a couple of minutes to adjust respiration and heart rate to handle the new activity level. During this period there is an *oxygen debt*. It represents a temporary shift from aerobic to anaerobic oxidation or a supplementation of aerobic activity by anaerobic activity. After several minutes, the body adjusts oxygen uptake for the new activity level. Steady state conditions denote that the oxygen uptake equals the oxygen requirements of active tissue. When the activity stops, there is a recovery period. The body returns to a resting or low activity level. The oxygen debt incurred at the start of activity gets repaid during the recovery period.

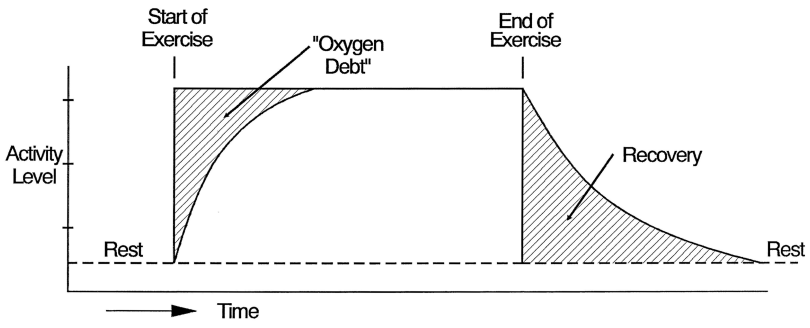


Figure 33-6. At the beginning of exercise the body develops an *oxygen debt* that is recovered when exercise ends.

TABLE 33-7 Energy Costs for Selected Activities[a,b]

Activity	Energy Cost		
	lb oxygen/hr	kcal/min	Btu/hr
Sleeping	0.04–0.05	1.1–1.2	260–280
Resting, sitting	0.07	1.7	400
Writing	0.07	1.8	430
Typing	0.09	2.3	550
Playing musical instrument	0.11	2.9	690
Golf	0.21	5.4	1290
Tennis	0.25	6.3	1500
Swimming at 1 mi/hr	0.26	6.9	1650
Cycling at 8–11 mi/hr	0.22	5.7	1360
Walking slowly	0.15	3.8	900
Shoveling sand	0.27–0.30	6.8–7.7	1620–1830
Chopping wood	0.29	7.5	1790
Digging	0.35	8.9	2120
Climbing stairs	0.47	12.0	2860
Marching double time	0.52	13.3	3160

[a]From P. Webb, ed., *Bioastronautics Data Book*, NASA SP 3006, Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 1964.
[b]Data are for a 167-lb person.

TABLE 33-8 Classification of Physical Work by Severity[a]

Grade of Work	Energy Cost			
	lb oxygen/hr	l oxygen/min	kcal/min	Btu/hr
Very light	< 0.10	< 0.5	< 2.5	< 595
Light	0.10–0.19	0.5–1.0	2.5–5.0	595–1190
Moderate	0.19–0.28	1.0–1.5	5.0–7.5	1190–1785
Heavy	0.28–0.38	1.5–2.0	7.5–10.0	1785–2380
Very heavy	0.38–0.47	2.0–2.5	10.0–12.5	2380–2975
Unduly heavy	> 0.47	> 2.5	> 12.5	> 2975

[a]From E. H. Christensen, *Ergonomics Research Society Symposium on Fatigue*, H. K. Lewis, Ltd., London, 1953, p. 93.

The body replaces materials lost in anaerobic oxidation and completes removal of waste.

Humans have energy production limits. Because there are limits to anaerobic capacity and duration, most activity involves aerobic oxidation. Maximum aerobic power is a function of maximum oxygen uptake. Physiological tests on treadmills or bicycle ergometers determine the maximum aerobic capacity. The maximum aerobic capacity varies with physical conditioning for an individual. One expression for an individual activity level is a percent of maximum aerobic capacity.

The energy produced during an activity is a function of oxygen uptake. Table 33-7 lists the energy cost for various activities for a person weighing 167 lb. Larger people have higher energy expenditures for the same activity. There is more body mass in motion. Smaller people have lower energy costs because of lower body mass.

Table 33-8 lists a classification of work by severity. Some work involves higher activity levels than other work. Associated with level of severity is the typical rate of oxygen consumption and calories burned. Units of measure for the rate at which people burn energy are kcal/min or Btu/hr.

Humans are inefficient at converting oxygen and fuel to useful energy. People can sustain efficiencies as high as 30% for only a minute or two. For most activities, the majority of energy expended converts to heat energy.

Application

Knowledge of energy cost for activities is important in designing physical work for people. Those designing physical work need to know human energy capacity and the associated physiological limitations. Energy cost is also important for assessing the dangers of thermal environments. The reason, discussed in Chapter 18, is that heat gain or loss must balance with the heat produced by the activity. Danger increases when there is a combination of activities and heat loads. Understanding energy costs is important when selecting personal protective suits, particularly full body suits. They may need to have cooling systems that remove waste heat from physical work. Wearing heavy clothing or clothing that restricts movement will increase energy expenditure levels above those shown in the tables. It is not uncommon for a full suit that restricts movement to double the energy expended without a full suit.

33-6 BIOMECHANICS

Description

Biomechanics is the application of mechanics to biological problems. It builds on anatomy, anthropometry and kinesiology. Kinesiology is the study of human movement. Biomechanics involves *kinematics*—the geometry and patterns of movement. Kinematic variables are displacement, velocity, and acceleration. Biomechanics also involves *kinetics*—the forces, energy, power, and work involved in movement.

Data tables provide population characteristics, such as link segment lengths, centers of gravity, moments of inertia, and mass. From data sources or measurements of people, one can determine linear and angular displacement and forces. These data allow development of analytical and computer models to describe or evaluate what is going on during various activities. Use of static and dynamic analysis facilitates evaluation of lifting and other tasks, such as pushing, pulling, turning, swinging tools, and other motions. Film and video techniques allow viewing of the dangers involved in motion-related activities. Figure 15-1 illustrates a static model. The revised NIOSH lifting equations (Equations

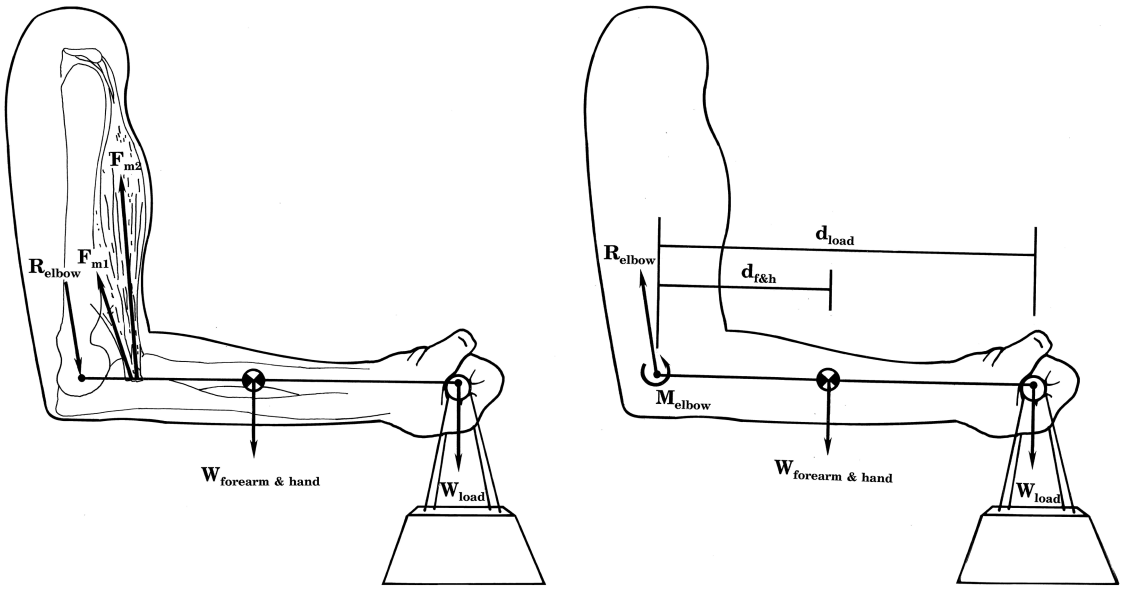


Figure 33-7. Example of a biomechanical analysis of the forearm and hand. In (a) the reaction force at the elbow must equal the sum of that produced by the forearm and hand. The muscles balance the moment created by the forearm and hand and the weight. The forces and moments are simplified in a free-body diagram (b).

(15-1) and (15-2) incorporate biomechanical knowledge into analysis of lifting tasks.

One can analyze some work tasks using standard methods used in engineering static and dynamic mechanics. Figure 33-7 diagrams the static loads in the forearm and hand created when lifting a weight. The muscles acting at the elbow must create reactive loads at the elbow. The weight of the forearm and hand together act at some distance (center of mass) from the elbow. For equilibrium, the load created by the segment masses must have a force and a moment at the elbow. The load on the hand creates an additional force and moment at the elbow. They transmit through the wrist joint. If the hand and arm were in motion raising the load, there would be additional inertial forces and moments added to the static components.

Application

There are many applications of biomechanics when considering safety problems. One application is analysis of resistance forces required for walking on surfaces without slipping. The longer the stride, the greater the frictional forces needed to prevent slipping. In a long stride, compared to a short stride, the legs extend forward and rearward further and have greater angles from vertical.

Another application is analysis of repeated motions involved in many jobs. Chapter 13 discussed cumulative trauma disorders and Chapter 15 included a discussion of manual materials handling problems and controls.

One can watch for other indicators of task-related biomechanical problems. Extreme joint flexion, unusual postures, large forces, forces not in line with body motion, vibration, and highly repetitive motions are all indicators of potential ergonomic problems. Table 33-9 is a checklist for ergonomic risk factors.

TABLE 33-9 Checklist for Ergonomic Risk Factors[a]

Upper Extremity	
Shoulder	Elbow held above mid torso
	Hand working above shoulder
	Reaching behind torso
Forearm	Inward rotation with bent wrist
	Outward rotation with bent wrist
	Repetitive twisting
Wrist	Palmar flexion
	More than 30 degrees extension
	Ulnar or radial deviation
Hand	Pinching
	Cold
	Vibration
High local force concentrations	Anywhere on skin, base of palms or back of fingers
Low Back	
Twisting	With or without load
Bending	More than 15 degrees with load
Load	Held large distance from body
	Large size or weight
Frequency	Continuous lifting throughout shift

[a]From T. J. Armstrong, "Ergonomics and Cumulative Trauma Disorders," *Hand Clinics*, 2: 553–565 (1986).

33-7 WORKPLACE AND EQUIPMENT DESIGN

Principles of Workstation Layout

Anthropometry, biomechanics, displays, controls, and other ergonomic components are integral elements when designing workstations and equipment. There are workstations for different postures, primarily standing and sitting. The discussion that follows includes only selected concepts, principles, and data for workstation design. Sanders and McCormick[3] identify four general principles for workstation layout: importance, frequency-of-use, functional, and sequence-of-use principles. These principles apply to location and arrangements of components. Items should be within reach and view. Items need organization that distributes tasks between the two hands or between hands and feet.

Importance Principle Designers must consider how important a component is to the overall operation of a system. Important components should be directly in front of an operator. There are several schemes to judge importance.

Frequency-of-Use Principle Another principle for layout considers how often someone uses components in operating a system. A display or control used frequently should have a location very convenient for the operator.

Functional Principle This principle suggests that functionally-related items should be close together. Conceptual factors may determine the groupings. An example of a concept is flow of fluid through a piping system. Another concept is grouping by similarity. For example, a functional relationship involves keeping all electrical system controls together or all hydraulic system controls together.

Sequence-of-Use Principle Another principle for layout considers the order in which one reads displays or operates controls. If an operator uses controls in sequence, the controls should be together and in sequential order.

Standing Work Surfaces

Workstation height is very important. Consideration of anthropometrics together with tasks will determine the preferred height. Table 33-10 lists recommended standing work surface heights for three types of tasks. For lifting tasks, the surface height is somewhat lower than for other tasks. There is a preference for lower heights if someone must press downward or generate downward forces. The lower heights make it easier to generate a downward force and keep the elbows nearly straight. For most standing height surfaces, the forearm should extend slightly below horizontal so that the shoulder muscles do not have to carry as much weight of the arms. It is best to have rounded work surface edges to distribute forces if arms rest on the surface or its edge. People seated at standing height workstations should have foot rests.

TABLE 33-10 Recommended Work Surface Heights[a]

	Recommend Height (in.)	
Type Task	Male	Female
Standing		
Precision work, elbows supported	43.0–47.0	40.5–44.5
Light assembly work	39.0–43.0	34.5–38.5
Heavy work	33.5–39.5	31.0–37;0
Seated		
Fine work or assembly	39.0–41.5	35.0–37.5
Precision work (e.g., mechanical assembly)	35.0–37.0	32.5–34.5
Writing or light assembly	29.0–31.0	27.5–29.5
Coarse or medium work	27.0–28.5	26.0–27.5

[a]From M. M. Ayoub, "Work Place Design and Posture," *Human Factors*, 15: 265–268 (1973).

Seated Work Surfaces

Preferred work surface heights for seated activities vary with task. Minimal muscle activity to support the arms occurs when the forearms are horizontal or sloping downward a small amount and when upper arms are vertical near the body. This forms a fairly neutral position for the arms. Muscles in extended and raised arms are more active and fatigue faster. Table 33-10 lists recommended work surface heights for seated work. Although standard desk heights are 30 in., the height should be adjustable if possible. Keyboard heights should be lower than the work surface height so that forearm and upper arm positions are as close to the neutral positions as possible. The slope of a keyboard is also important. If it has too great a slope, a user must flex the wrist, making keying more difficult. Keeping wrists nearly straight with the forearms reduces the strain from flexed wrists.

Seating

There are many anthropometric dimensions important for seating. Where possible, there should be adjustable seat pan height and back rest height. Most of the weight of the torso bears on the interface between the ischial tuberosities of the pelvis and the seat pan. Part of the leg weight carries to the floor through the feet. Cushioning material and seat pan contour help distribute the weight over as large an area of the seat pan as possible to minimize concentration of loads. With concentrated loads, it is possible to interrupt blood circulation. The seat pan height should be low enough so leg weight does not bear heavily on the front edge of the seat pan and

TABLE 33-11 Recommended Dimensions for Office Chairs[a]

Seat	
Height from floor	16–20.5 in.[b]
Width (breadth)	17.7 in.
Length (depth)	15–17 in.[c]
Pan angle	0–10° or adjustable in this range
Seat back-to-pan included angle	90–105°, adjustment preferred
Backrest	
Height	Variable with task and back angle
Width	At least 12.5 in. in the lumbar region
Armrest	
Inside distance	At least 17.2 in.

[a]From ANSI/HFS 100, *Human Factors Engineering of Visual Display Terminal Workstations*.
[b]Operators with popliteal heights of less than 16 in. may need a footrest.
[c]Chairs with seat depths exceeding 16 in. shall provide relief to the back side of the knee (such as contouring).

interfere with circulation. Some people with short legs may need foot rests when seat pans are not adjustable or are not low enough. Seat pan depth should be adjustable. There should be forward and backward movement of the seat back. The goal is to provide good support for the lower and middle part of the back. Table 33-11 lists recommended dimensions for office chairs. Look for adjustable features to accommodate different sized users.

Other factors are important in seating. Too often there is no place for seated factory workers to place their legs. As a result, they sit with their legs turned and torsos twisted. That may lead to back problems. If workers must turn from side to side, seat pans should swivel. For some activities, such as driving a truck, vibration absorption is essential.

To get up from a seated position requires positioning the center of gravity of the body over the feet. Someone must move forward in a seat to stand up. Some people, particularly the elderly, have problems getting out of low, soft seating. It is difficult to slide forward toward the front edge to begin standing up. Chairs with arm rests help people to stand from a seated position. Some chairs, called lift chairs, have special features that assist an occupant from a seated to a standing position.

Seats in automobiles cannot have the seat pan at the desired height because of auto size limits. Many vehicles now have adjustable seat height, seat tilt and back rest tilt. Those adjustments allow drivers and passengers to find comfortable positions.

The support system for chairs is important for safety. Office chairs that move around and have only four legs and casters can tip quite easily. Most office chairs have five support legs and casters to improve stability.

Computer Workstations

Computer monitors may cause eye and vision problems. Workers with eyeglasses need the correct prescription and correct viewing distance in the prescription. If someone wears bifocals, the positioning of the close prescription may need vertical adjustment in the lens so viewing a monitor does not require turning the head upward.

Having the right monitor prevents many problems with prolonged viewing. Most monitors today have non-glare surfaces to minimize glare from overhead lighting. Digital monitors with LCD displays provide higher resolution and more precise colors than previous analog cathode ray tube monitors.

If a monitor has bright background colors, it can create afterimages, called the McCollough effect. A user may need to adjust brightness and contrast to reduce the light-dark intensity.

There are also problems of monitor locations at workstations. It is important to get a monitor screen and a keyboard at the right heights. Improper workstation layout can lead to arm, shoulder, neck and back muscle fatigue and pain.

The first adjustment is getting a chair height correct. Next is getting a work surface height correct. The work surface height may involve monitor height and viewing angle. The normal viewing angle is about 15 to 20 degrees below horizontal. Some people are not comfortable looking straight ahead. Looking up at a monitor creates muscle fatigue and discomfort. As noted earlier, the keyboard height should allow the forearms to be horizontal or slightly lower and the upper arms to hand naturally, almost vertical. A screen and keyboard used for long periods should be directly in front of the worker to avoid turning the head or body.

For people who work for extended periods (more than one or two hours continuously) at a computer workstation should take breaks, change activities, or complete some stretching exercises. Several resources offer a range of exercises for computer workers.

With the expanded use of computers, keyboards have become extremely common control and data entry devices. There are many different models available. Some models have each half of the keyboard slightly bent from horizontal. This feature positions the keys to be in line with the arms and hands. Arms and hands at one's side are at an angle and not perpendicular to a keyboard. An ergonomic goal is to keep wrists straight, not bent. A slightly bent keyboard accommodates this natural position of a wrist.

Workers should change tasks to reduce the intensity of keyboard data entry. They should find opportunities to stretch and relax the muscles and tendons involved in typing. People involved in deciding on data entry should consider other methods of data entry other than use of keyboards. Other data entry technologies include bar codes, image scanning, optical character recognition, hand printing and writing recognition, and other scanner technologies. Use of

other technologies avoids keyboard data entry and ergonomic issues associated with keyboard entry. Use of alternate data capture technologies may improve data accuracy and productivity.

Designing for Maintainability

Too often designers think of normal use and operation of equipment and they forget the tasks related to maintenance and repair. Designs that incorporate maintainability concepts will reduce errors during maintenance activities. Designing for maintainability will help prevent unnecessary damage to components because workers cannot see or reach into areas where they need to do work. They will reduce accidents and injuries resulting from maintenance and repair work.

Access points and panels should have convenient locations. Openings should be large enough for the work involved. Small holes allow access by hands and arms. Large openings allow access for a head, shoulders or an entire body. In some cases, there should be viewing ports so a worker can see hands.

There are ways to code components so someone does not confuse them. There are ways to design connectors and fittings so only correct mating parts connect. That prevents errors. References listed in the Bibliography provide insight into many techniques for incorporating human factors principles into maintainability. Many maintainability features involve safe maintenance and repair work.

33-8 DESIGNING FOR THE WORK FORCE

The Changing Work Force and Population

Work force demographics will change. During the last few decades, the number of women in the workforce has risen significantly. Many women fill traditionally male jobs. The average age of workers in the United States continues to increase. Many people stay in the work force beyond minimum retirement age. In addition, the number of people in the work force with disabilities continues to increase along with the range of disabilities. Products and work places must accommodate a wide variety of buyers and employees. All of these buyer and worker characteristics have implications for safety and health.

Women

Women are capable of most jobs men can do. One issue has been the availability of personal protective equipment that fits properly. Suppliers continue to offer greater variety than in the past. Work stations must adjust to accommodate the size and physical capabilities of women. Task designs may need adjustment along with work station furnishings. Work stations, furnishings, tools, and equipment need to adjust to fit women and their capabilities.

The Elderly

The United States workforce continues to get older. A safety dilemma is recognizing the reduced capabilities of some older workers and adjusting tasks, tools, equipment, and furnishings to fit them. Many older people are likely to have less strength, range of motion, and stamina. They may have reductions in vision and hearing capabilities. Most people over the age of 55 have some degree of cataracts. For some people physical conditioning may help to retain capabilities. In most cases, there are glasses and hearing devices that restore capabilities. For some people there are medical solutions that restore lost capabilities.

The Disabled

Medicine today extends the life of many people with disabilities. For example, today the survival rate for victims of automobile crashes is much higher than in the past. The unfortunate part is that many of these victims have some permanent disability. Today people with disabilities from disease and injury are part of the mainstream of society. Federal and state laws require that public buildings, transportation, and certain housing include accessibility for the disabled. Employment laws prohibit an employer from denying employment to a disabled person because the workplace cannot accommodate them. For example, there is a federal law that mandates that federal agencies assure accessibility of office equipment (including computers) accessibility to disabled individuals.[4] The Department of Justice issues standards and regulations related to accessible design.[5]

33-9 STANDARDS

Most anthropometric data result from particular studies and appear in publications. Some military organizations in the United States and other countries publish anthropometric and ergonomic design standards for military populations.

Note 4 cites the U.S. Department of Justice publishes regulations and standards for accessibility for the disabled. For example, the Department of Defense has a long-standing

publication on human engineering design that undergoes periodic updates.[6]

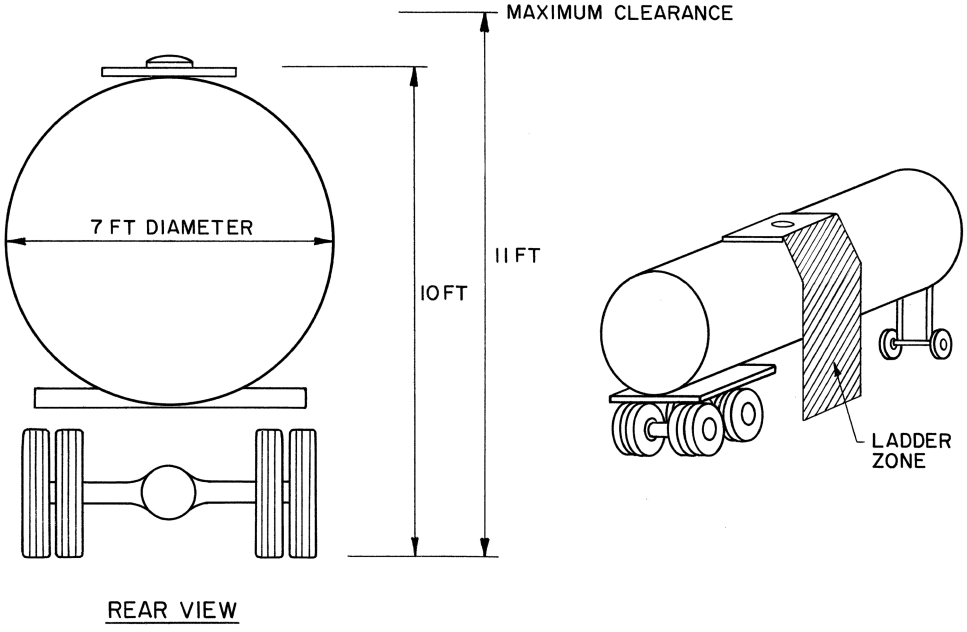
Some organizations also publish design standards or guides. For example, the Society of Automotive Engineers (SAE) publishes design standards for many kinds of commercial and recreational vehicles.[7] Some standards cover displays, controls, ergonomic fit and other design factors for users. SAE also offers other publications related to vehicle design.

The Human Factors and Ergonomics Society (HFES) publishes several standards[8] for design of equipment and workstations through the American National Standards Institute. HFES also offers other publications on a wide range of ergonomics matters.

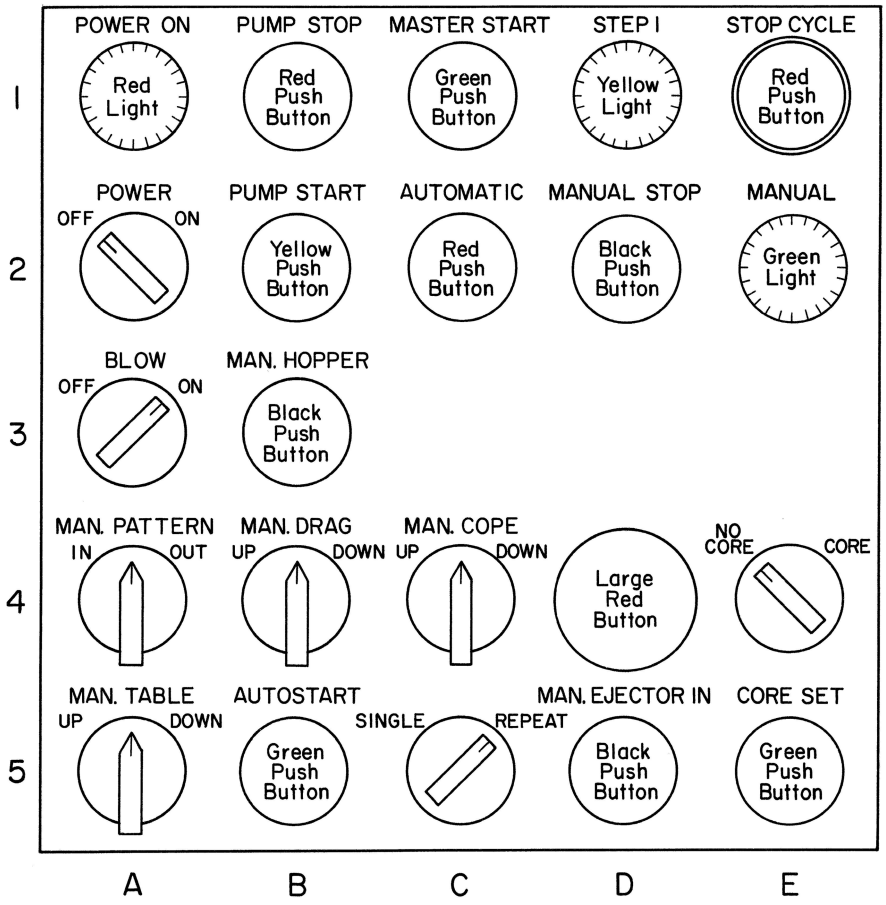
There are also private organizations that compile directories of worldwide human factors and ergonomics standards.[9]

EXERCISES

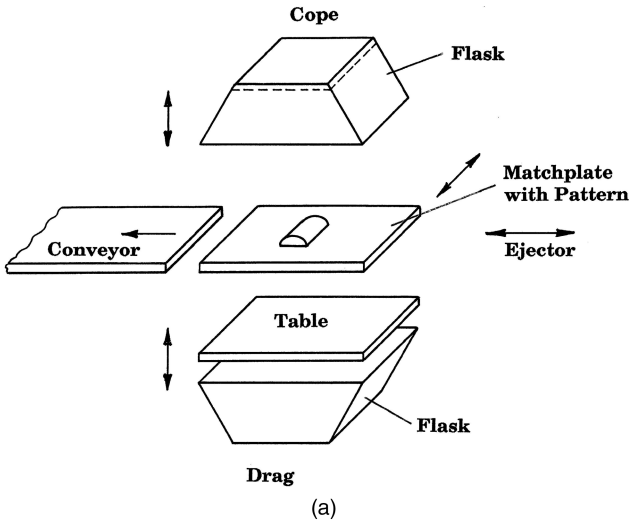
1. A warning sign must be readable from a distance of 20 ft. Sometimes there are unfavorable reading conditions, but above 1 fc. The message is important. How high should the letters be?
2. You are to design a computer workstation that includes use of a keyboard from a seated position. Identify the recommended dimensions or range of dimensions for the following:
   - **(a)** seat height
   - **(b)** seat depth
   - **(c)** seat pan slope
   - **(d)** back rest slope or angle
   - **(e)** clearance between the seat pan and the underside of the work surface
   - **(f)** floor-to-table distance
   - **(g)** keyboard height
   - **(h)** viewing distance
   - **(i)** viewing angle from horizontal
3. You are to design access to the top of a tank trailer. The vehicle operator must climb to the top to check on filling and to seal the hatch. A ladder device must be at the midpoint along the trailer length to get to the fill hatch on top. Sketch your design solution. Identify key dimensions and note the source of your data. The figure labeled Exercise 33-3 shows the basic dimensions of the truck.
4. You are to redesign and reconfigure the control/display panel shown in the figure labeled Exercise 33-4a. The panel is part of a machine that makes sand molds for castings. The panel contains lights, push buttons, selector switches and selectors that center themselves in a neutral position when not operated. The panel has a five-row and five-column layout. The solution should follow principles of ergonomic design and need not



Exercise 33-3. Diagram for Exercise 33-3.



Exercise 33-4a. Current panel layout for Exercise 33-4.

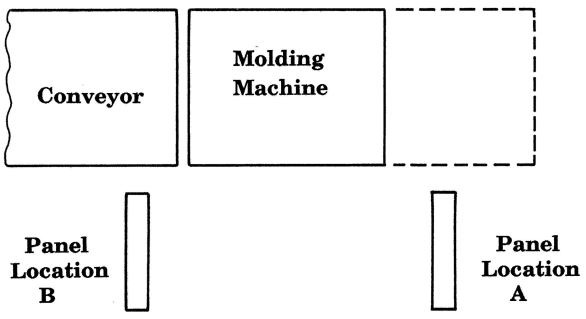


(a)

Exercise 33-4b. Functional diagram of machine components for Exercise 33-4.

fit in the same panel. The functions of the machine are as shown in the figures labeled 33-4b and 33-4c. Table 33-12 lists the automatic and manual modes for the molding machine control components for the sequence of functions.

5. Locate the software that adjusts the operation of a computer mouse or game control. Change each setting to see what impact the adjustments have on the ability to



(b)

Exercise 33-4c. Plan view of machine and panel layout for Exercise 33-4.

TABLE 33-12 Data for Exercise 33-4: Functional Sequence for Mold Making Machine

Function	Components Involved		
	Selector Switch	Push Button	Light
ENERGIZE MACHINE			
Turn power on	**A2**		**A1**
Turn sand pump on		**B2**	
Turn blow valves on	**A3**		
SELECT OPTIONS			
Single or repeat	C5		
Core or no core	E4		
Automatic cycle or		**C2**	
manual (default) cycle		**E2**	
POSITION TO START (Step 1)			
Manual step the cycle to step 1		Cl & D2 together	
When at step 1			**D1**
START CYCLE (AUTOMATIC) (May be single or repeating cycle)			
Autostart		C1 & B5 together	
Stop cycle to insert core (see core/no core option) and continue cycle		**E5**	
Cycle Complete			**D1**
To repeat cycle automatically (see single/repeat option)			
To stop at end of single cycle (see single/repeat option)			
STOP OR INTERRUPT AUTOMATIC CYCLE			
Stop cycle		**E1**	
.START ACTIONS FOR MANUAL MODE (Default)			
Manual step to step 1		Cl & D2 together	
Manual pattern movement		Cl & A4 together	
Manual drag movement		Cl & B4 together	
Manual cope movement		Cl & C4 together	
Manual table movement		Cl & A5 together	
Manual ejector		D5	
Manual hopper		**B3**	
STOP MANUAL ACTIONS			
Release the buttons			
DEENERGIZE THE MACHINE			
Turn blow valves off		A3	
Turn sand pump off		B1	
Turn power off		A2	
EMERGENCY POWER OFF		D4	

use the control device effectively. Identify what control parameter each adjustment affects.

REVIEW QUESTIONS

1. What does the word ergonomics mean?
2. Describe what the field of ergonomics is about.
3. How is ergonomics applied?
4. Identify three things that people are good at and three that machines are good at.
5. Name two fundamental principles of ergonomics.
6. What is anthropometry?
7. Much anthropometric data are in percentiles. Describe how to apply percentile data in design.
8. Name three principles for applying anthropometry in design.
9. Describe the six elements in the people-machine interface.
10. Name two kinds of displays.
11. What are three characteristics that display characters should have?
12. What is coding? Give three examples.
13. What is compatibility? Give three examples.
14. What is the difference between pursuit and compensatory tracking tasks?
15. What is the difference between discrete and continuous controls?
16. What is the control/display ratio?
17. Why is control movement important in control tasks?
18. What are four methods for creating control resistance?
19. Describe five methods for preventing accidental activation of controls.
20. What are the two main ways in which the body converts fuel to energy output?
21. Describe the significance of energy expenditure when wearing personal protective clothing, particularly full suits.
22. What is biomechanics? Kinesiology? Kinematics? Kinetics?
23. What are units of measure for kinematics? For kinetics?
24. What are the four principles for workstation layout?
25. Why is maintainability an important part of ergonomics?
26. Name three changes in the work force and population that place greater emphasis and demands on ergonomics in design of products and workplaces.

NOTES

1 www.nytimes.com/1987/07/22/us/osha-seeks-2.59-million-fine-for-meatpacker-s-injury-reports.html

2 N. Diffrient et al., *Human Scale*, MIT Press, Cambridge, MA, 1981.

3 Mark S. Sanders and Ernest J. McCormick, *Human Factors in Engineering and Design*, 7th ed., McGraw-Hill, New York, 1993.

4 Public Law 99-506 (1986), Section 508, Reauthorization of the Rehabilitation Act of 1973.

5 *2010 ADA Standards for Accessible Design*, U.S. Department of Justice, 2010. www.ada.gov/regs2010/2010ADAStandards/2010ADAstandards.htm

6 MIL-STD-1472G *Department of Defense Design Criteria Standard: Human Engineering*, Revision G, January 11, 2012.

7 http://standards.sae.org/

8 www.hfes.org/web/Standards/standards.html

9 www.interface-analysis.com/IAA/ergonomics-standards.html

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PART V

MANAGING SAFETY AND HEALTH

PARTS III and IV of this book focused on recognizing, evaluating, and controlling hazards. When working with planning, design, or operations of an equipment item, process, or facility, there will be many hazards. Once identified, an issue is how to organize them and decide which controls to implement. This section of the book addresses methods for systematically identifying, organizing, and controlling hazards. That involves management.

Engineers need to convert their ideas so managers can understand. They need to talk "management talk." Engineers need to understand how to have safety and health controls implemented in an organization. They need methods for organizing a wide variety of controls and establishing priorities for them. Management needs priorities communicated in management terms, not only in engineering or safety terms. Engineers need to understand the fundamentals of creating an organizational culture that places safety at the top of organizational priorities.

This part of the book covers two main areas. The first is incorporating safety and health into an organization. Management of an organization plays an important role when implementing controls for hazards. The methods begin with comprehensive hazard identification and assessment. Many groups call these activities risk assessment and risk management. The methods continue by getting organizations and their leaders to incorporate safety into their daily operations. This section includes a discussion of safety management systems (SMS). More and more organizations and industry groups are defining orderly and systematic approaches for managing safety and health within entire organizations.

The second main area covers methods and techniques for identifying and managing hazard recognition and safety information essential to managing the breadth of safety and health. These methods help the engineer organize a wide mix of hazards and controls and present them in forms that management understands.

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CHAPTER 34

RISK, RISK ASSESSMENT AND RISK MANAGEMENT

34-1 RISK AND LOSSES

In life, there are events that result in gains or losses for people and organizations. Most people do not want losses. However, many people will take a chance at achieving a gain. Risk involves avoidance of losses and unwanted consequences while pursuing opportunities to achieve, become better or increase income.

There are many definitions for risk. Rowe[1] defines risk as the potential for realization of unwanted, negative consequences of an event. Risk aversion is action taken to control or reduce risk.

For safety and health, a common definition of risk infers a quantitative concept. In safety and health, risk usually infers the probability or likelihood of an adverse event and the severity of the event's consequences. There are two aspects: frequency and severity. Frequency is the probability of an event's occurrence, such as once per week, once per year, or once every 100 years. Some prefer a probability view for frequency, such as once for every 10, 100 or 1000 similar events.

Severity is the potential loss when an event occurs. Some express potential losses in human terms, such as loss of life, serious injury, serious illness, number of cancer cases or similar terms. Some express a loss in financial terms. Examples are dollar value of production interruption, cost to replace lost equipment, cost to replace facilities, or cost of medical treatment, pay compensation for those injured or increased insurance premiums. Some express loss in legal terms, such as number of claims or lawsuits and the liability incurred. For a company, a loss can be a reduction in public image or product image or lost market share.

There are multiple factors related to the risk concept. One factor is using risk to identify the hazards, events and consequences one must avoid. Another is development of formal methods for preventing, avoiding or dealing with risks and risk derived events. Examples are risk assessment and risk management methods. These methods often incorporating risk assessment into strategies for anticipating and preventing unwanted events. One of the applications is incorporating risk as part of safety management systems, covered in Chapter 35.

Risk assessment and management apply to general operation of a business and business decisions. The losses and unwanted consequences for a business are ultimately financial. The idea of risk for a business has a broad meaning that implies any kind of detriment to a business. Companies apply risk to financial decisions, security of trade secrets, security of data and computer systems, and a range of other potential business losses. Risk also applies to managing losses associated with accidents, human error, and health exposures. Often risk is part of legislative and regulatory strategies.

34-2 RISK COMPLEXITIES

There are many ways organizations and individuals deal with risk and risk concepts. This section will explore some variations in the application of risk concepts.

Regulatory Aspects of Risk

Risk is an important consideration for government leaders who struggle with creating laws and regulations. A principal role for government is protecting the health, safety, and welfare of the public. A legislative question is what is the most effective way to assure safety in the workplace, in products or for public safety.

Regulatory Methods Chapter 5 discussed a legislative strategy that originated in the British Parliament for regulating safety and health for the workplace in the United Kingdom. The strategy resulted from the early 1970s Committee on Safety and Health at Work led by Lord Robens. The strategy established the role of government in achieving safety and health at work. The strategy was adopted by several other commonwealth countries after its introduction in the United Kingdom.

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The Committee Report recognized there is too much law and associated regulations. It also recognized that the primary responsibility for prevention lies with those who create the risks. Those responsible are the management and the workers. It concluded that a more effective self-regulating system is preferable to trying to achieve safety and health through negative regulation.[2] In summary, this led to a system in which there are minimal government laws and regulations. The system assigned employers primary responsibility for managing risks of workplaces. It led to performance standards from government and a limited number of prescriptive standards. The approach applied to both workplace and product regulations.

In 1972, Lord Drumalbyn summarized the Committee Report recommendations:

> These and other recommendations are designed to create a framework within which employers and work-people jointly can achieve a more self-regulating system for securing safety and health at work; in which the inspectorates can be used more effectively in assisting employers and work-people as well as concentrating more effectively on particular serious problems; and in which statutory regulations can be kept as simple and up-to-date as possible.[3]

The Report also emphasizes the importance of *duty of care* under English and Commonwealth laws. A duty of care arises when an individual or group undertakes an activity which could harm another physically, mentally, or economically. Workplace safety and health for employers involved duty of care.[4] This concept even extends to international business travelers.[5]

In contrast, the legal and regulatory system in the United States for safety and health that emerged emphasized government issued prescriptive standards for many details of workplaces, work, products, systems, equipment, and facilities. The Occupational Safety and Health Administration and other agencies regulating safety and health produce few performance standards. Employers and manufacturers also rely on government and consensus standards which prescribe details for workplaces and products.

Regulatory Strategy One difficulty for governments at the legislative level and regulatory level is knowing how best to respond to risk. Many factors become involved in deciding what risks need public protection and what level of risk forms the basis for laws and regulations.

In his book,[6] David Vogel discusses the foundation for regulatory actions. He points out that for about three decades beginning about 1960 the United States was one of the first countries to identify new health, safety, and environmental risks. They led to rules for new drugs, pesticides, food safety, chemicals, automobile emissions and other risks. During that time European risk regulations lagged. There were some exceptions. However, about 1990, there was a shift in which part of the globe led in regulations for new risks.

Vogel points in part to the difference in the criteria for establishing regulations. In general, the U.S. regulations had a sound science basis. For Europe, there was a shift to a *precautionary principle*. It relies more readily on public fears and perceived risks. The risk assessment criteria differ. For the United States, if there is no proof for a risk, there is little justification for regulating them. The risk should be allowed. For Europe, if there is a chance for a risk, it should not be allowed.

The precautionary principle provides a justification for society to act on risks and uncertainty when scientific evidence is not available to determine that a risk is acceptably safe. One definition for the precautionary principle comes from the Wingspread Conference of 1998[7]:

> Precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.

The EU promoted the precautionary principle in an official communication in 2000.[8]

Vogel also discusses Type I and Type II policy errors. A Type I policy error is having overly stringent regulations he calls false positives. A Type II policy error is having insufficiently stringent regulations called false negatives. Both types of errors can cause harm. A false positive can impose unnecessary costs on producers and consumers, restrict technological innovation and increase public fears. A false negative can expose citizens and the environment to preventable risks.

Setting public policy for safety and health is difficult and complex. Legislators must weigh many competing factors in reaching decisions about the risks and levels of risks to regulate. United States Supreme Court Justice Stephen Breyer discussed the regulatory challenges for health risks.[9] He discusses risk assessment and notes the issues related to risk perception. The public perception of risks is often different from scientific risk perceptions or perception by regulators. He points out the cost to implement regulations is also an important consideration. The gain in risk reduction may be very expensive. He provides a detailed discussion of many issues surrounding use of regulations to reduce health risks.

Risk and Technology

Much of the discussion in this book centers around the hazards people face at work, in products, at home and in outside activities. For those responsible for safety through product design or operations and management of work, an approach is looking at the risks associated with each hazard. This chapter addresses risk and risk assessment.

Many of the risks involve technology. There are risks associated with each technology. There are also benefits. A

responsibility is identifying the risks and establishing protection. A key issue is "How much risk is acceptable?" As noted in Chapter 3, a similar question is "How safe is safe enough?" Controlling risks or reducing them will incur costs.

Technology has created benefits. During the last 100 years, life expectancy has nearly doubled. Technology has contributed a lot to that benefit.

As H. W. Lewis points ou,[10] technological risks are real. We must identify them, understand them, measure them, assess them and manage them. How the public perceives risks may not be the same as perceptions of technical people or politicians. In many cases we have a lot of difficulty in measuring them because scientific study is incomplete. In trying to assess them, there is little experience and few cases for making estimates of likelihood or severity for some risks. In some cases there is incomplete knowledge for deciding how to manage them. Information may be too limited to estimate costs to reduce risks or to estimate the degree of risk reduction.

Yet technological risk requires a balance with benefits. One of the highest technological risks for people involves automobile accidents. However, most people would strongly object to giving up automobiles. The answers are not always easy to find.

The growth of technology seems to be exponential. Along with the rapid increase in technologies in human lives is the complexity technology brings. Very often combinations of technologies produce new risks that individual technologies alone do not offer. That creates even greater challenges for safety and health.

In his book,[11] Charles Perrow discusses the challenge of risks related to complex systems. An adverse event often results from a combination of little events. For some small events there is *redundancy*. There is an alternative so an event does not lead to a more serious consequence. In safety engineering there is a need to find redundancy in systems. Chapter 9 discussed redundancy as a preventive strategy. It introduced single-point failures, a lack of redundancy.

Perrow also points to the concept of *coupling*. One small event may link to another event. The second event may have more serious consequences than the first. For example, a decision error that leaves combustibles sitting near a gas flame in a laboratory may lead to a large fire. He distinguishes *tight coupling* and *loose coupling* between events.

A tight coupling event is one event leading to a second, more serious event. The second event does not normally occur on its own. Those focusing on the first event are not likely to think about the second event. One example is Case 17-5. In the BP refinery accident that killed 15 people, a contractor positioned a temporary work trailer near a hazardous area. Positioning the work trailer farther away would have prevented many of those deaths when there was an explosion in the refinery. The trailer location was not an issue until there was an unexpected explosion.

Loose coupling occurs when there are two or more adverse events at the same time but one does not cause the another.

Technological risks often stem from the combination of complexity and coupling. What begins as a small event can lead to a catastrophe. With complicated designs, it is hard to anticipate the possible interactions. Installing safety devices and redundancy may not prevent all of the event sequences. Thus, risks introduced by complex technologies often are difficult to assess and manage. Chapter 36 will introduce some methods used in system safety for dealing with complex risks. Chapter 35 will discuss process safety management, introduced in Chapter 24, and methods derived from system safety practices.

Risk and Business

From a business perspective, application of risk concepts involve two main elements. One is risk assessment. The other is risk management. Risk assessment involves methods that identify business risks. Among the business risks are safety and health risks for employees, customers, and the public. There are also risks to the equipment, property, and financial condition of a business. Risk management involves evaluating identified risks and making decisions about how to handle them from a business perspective.

A discussion of risk assessment and risk management is part of this chapter. Recently there has been a significant expansion of these concepts for managing safety and health. Many industries and organizations have adopted safety management systems, discussed further in Chapter 35. Safety management systems (SMS) incorporate risk assessment and risk management.

Risk and Insurance

Risk is a basic element of insurance. The Insurance Risk Management Institute defines risk as "the insured or the property to which an insurance policy relates."[12] It also recognizes risk as the "uncertainty arising from the possible occurrence of given events." The latter definition is close to the meaning primarily used in safety and health.

An insurance company may specialize and provide insurance policies only for certain kinds of risks. A business or individual will seek financial protection against property loss, death, injury or financial loss based on certain kinds of risks. An insurance company will evaluate the risks and make estimates of the likelihood and severity of events leading to a loss. It will decide if it wishes to offer insurance and determine the premiums for a customer based on the risks. Underwriting is the process an insurance company uses to determine whether to accept a risk, the amount of insurance to offer, and at what price.

For the insurance industry, another aspect of risk is loss control. Loss control is controlling conditions that can lead to a loss. It is part of risk management. For an insurance company, loss control is helping insured customers prevent loss producing events. Few losses means few insurance claims. From a safety perspective, loss control helps clients manage safety and health, recognizes hazards and implements preventive measures. The measures eliminate accidents and incidents that create personal, property or financial losses for both parties. When loss control is effective, the insurance company and the insured gain benefits.

Risk Perception

Not everyone perceives risks the same. There are many factors that influence individual risk perceptions. There are technical aspects and human aspects in risk perception. Recall that risk involves the likelihood and severity of events. Those elements influence various people differently.

People will differ in perception based on technical considerations. For example, some people have difficulty applying probability and numbers. People will differ in how they interpret statistics, sample sizes in studies and numbers that represent risk or benefits. Some people will simply overrate the danger of a chemical, for example, because it has had adverse publicity. There are many examples. Some case studies in other chapters provide illustrations.

In his book on risk perception, David Ropeik identifies risk perception factors.[13] The factors link to whether someone is afraid and how the brain judges the presence of danger. The more one is in control of a situation, the lower the fear. Usually, there is more than one risk perception factor involved. Other mental factors, including experience, education, and lifestyle, also influence risk perception.

The Risk Perception Factors include:

1. *Trust*. Fear goes up or down depending on the people and organizations we trust and who communicates a message about risk.
2. *Risk versus benefit*. The greater the perceived benefit, the smaller the perceived risk. The lower the perceived benefit, the greater the perceived risk.
3. *Control*. The more control we think we have, the safer we feel.
4. *Choice*. Imposed risks are less acceptable than voluntary risks.
5. *Is the risk natural or human-made?* People tend to accept natural risks more readily than risks created by humans in products and processes.
6. *Pain and suffering*. People worry about the potential for pain and suffering, even if a risk has a very low probability.
7. *Uncertainty*. The more uncertain we are about a risk, the more afraid we are likely to be. (In part, this factor led to the precautionary principle.)
8. *Catastrophic or chronic*. Loss of multiple lives in one place at one time is frightening, while frequent deaths from distributed causes and scattered over time are less frightening.
9. *Can it happen to me?* Any risk feels bigger if you think it could happen to you, even if the likelihood is remote.
10. *Is the risk new or familiar?* People worry more about a risk that is new or new to them than a risk which they are well aware of.
11. *Risks to children*. Any risk to children evokes more fear than the same risk to adults.
12. *Personification*. A risk creates more concern if the risk involves a real person. People are more afraid of a risk, if they know the person.
13. *Fairness*. If a risk threatens someone or a group unable to protect themselves, people perceive the risk as worse.

Others have studied risk perception. Table 34-1 lists risk perception factors that influence acceptance of risk situations. There are many factors that affect people's estimates of risk. They may think that risk is greater than it really is or less than it really is. Table 34-2 lists several factors that affect the value people place on risk.

TABLE 34-1 Risk Perception Factors Affecting Risk Acceptance[a]

More Acceptable	Less Acceptable
Voluntary	Involuntary
Natural	Human-made
Controllable	Not controllable
Delayed effect	Immediate effect
You and yours	Me and mine
Essential	Nonessential
Off-the-job	On-the-job
Misuse hazard	Proper use hazard
Affects few	Affects many
Effects reversible	Effects irreversible
Sensory perception	Unable to sense
Relates to self-worth	Does not relate to self-worth
Greater benefits	Lesser benefits
Experience	No experience
Understood	Not understood
Higher cost to fix	Lower cost to fix
Low consequence	High consequence
High probability	Low probability
No alternatives	Alternatives

[a]J. R. Buys, "Risk Perception, Evaluation, and Projection," Informal Report EGG-SHS-5975, Idaho National Engineering Laboratory, Idaho Operations Office, U.S. Department of Energy, Idaho Falls, ID, August 1982.

TABLE 34-2 Risk Perception Factors Affecting Risk Estimation[a]

Underestimate	Overestimate
Known	Unknown
Understood	Not understood
Common	Uncommon
Mundane	Dramatic
Little media coverage	Much media coverage
Noncontroversial	Controversial
Me in control	You in control
Voluntary	Non-voluntary
Fun risks	Work risks
Few injuries/events	Many injuries/events
Sensory perception	Unable to sense
Benign experience	Hurtful experience
"Scientific"	Not "scientific"

[a]J. R. Buys, "Risk Perception, Evaluation, and Projection," Informal Report EGG-SHS-5975, Idaho National Engineering Laboratory, Idaho Operations Office, U.S. Department of Energy, Idaho Falls, ID, August 1982.

Risk Taking Behavior

For many activities the likelihood of producing an accident or injury is low, but possible. People will often take a chance, even when they know that an activity is risky. There are numerous examples of risk-taking behavior. Many examples appear as humorous on television shows and on YouTube files.

Consider texting and driving. In most cases, someone who is driving and trying to text on their phone will not have an accident. However, the distraction can lead to a serious accident. Similarly, some people do not wear seatbelts. They ride in their car time after time without incident. The seatbelt is useful only when there is an accident. Such reasoning may suggest to others there is little risk when operating a machine without a guard in place. The observation is workers do it often without an incident.

People who are risk takers generally have accidents more frequently. They have higher absentee rates from work than those who are not risk takers.

Various circumstance influence the likelihood of risk-taking behavior by individuals. Risk perception greatly influences risk taking and risk acceptance. For example, most people will take greater risks when they have a choice about safety and protection. The same people do not want to take risks when employers require safe procedures.

Individuals are less likely to take risks when they are anxious. They are more likely to take risks when they understand what is going on. For example, many people are afraid to undergo surgery. However, the more an individual knows about a surgical procedure, the less reluctance there is to undergo the surgery. Employers that measure hearing reduction with hearing protection programs and give wearers the test results find increased cooperation with hearing protection programs.

Individuals are not willing to take risks when the status quo has strong value. Because there is a fear of the unknown, people are reluctant to change. They find satisfaction with the way things are.

There are differences between group risk-taking behavior and individual risk-taking behavior. For example, fear tends to trigger group behavior. When something arouses fear, people choose to be together with others. Conversely, when people are anxious, they choose to be alone. Examples of groups are family, friends, work groups, command groups, or groups structured around coping with common or shared stresses or threats. Groups have informal structures, whereas organizations have formal structures.

34-3 RISK ASSESSMENT

Terminology for risk, risk management, and risk assessment is not consistent among sources. For some sources, risk assessment is a portion of risk management. Some sources separate risk assessment from risk management.

The two tasks may involve different groups or organizations. For example, when considering legislation, those crafting regulatory policy depend on the work of scientists, industry groups, and interest groups to identify and evaluate the risks.

Risk assessment involves identification and analysis of risk. Some models include risk evaluation. Other models include evaluation as part of risk management.

For safety and health, risk assessment begins with hazard identification and identification of threats and hazard-driven events affecting people and property. Chapters in Parts III and IV of this book addressed hazard recognition and controls in detail. The American Society of Safety Engineers operates a Risk Assessment Institute that provides help with risk assessment.[14]

After identifying risks, the next step in risk assessment involves risk analysis. Figure 34-1 illustrates a common way to evaluate risks. Someone must evaluate each risk for likelihood or frequency of occurrence. Analysis must also consider severity or consequences for each risk. In insurance, risk mapping is the same as risk assessment with severity focused on financial consequences. Many organizations use charts similar to Figure 34-1 as decision-making aids. An increasing number of organizations and employers provide similar risk assessment charts for workers and managers to help them judge workplace risks.

Risk assessment is not independent of the process or the personnel involved. The method used as well as the participants, can affect the risk assessment. Sometimes, people affected by a risk are not participants. That can create significant biases in the process. As noted earlier, not all

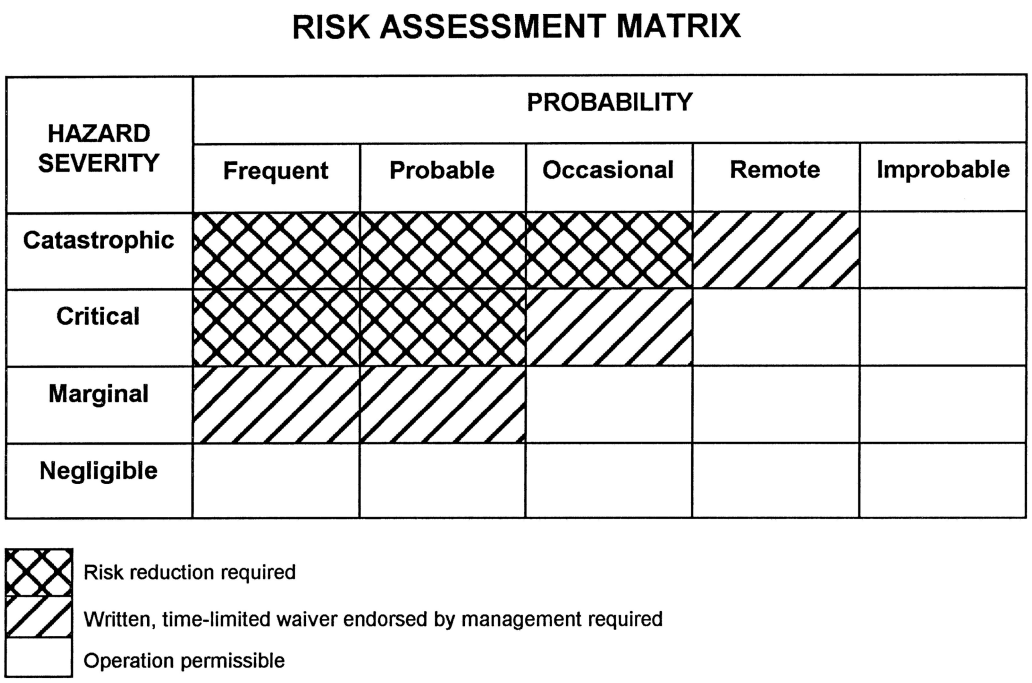


Figure 34-1. A risk reduction decision matrix.

individuals or groups perceive risks the same. Analysis may be subjective based on knowledge of those participating in risk assessment. Participation should include workers and managers with experience with hazards and risks for a business or operation.

Figure 34-2 is a diagrammatic representation of risk assessment. The illustration shows risk assessment with two main components. This diagram includes risk determination and risk estimation. Risk determination includes identifying risks and risk estimation. These are the same two steps others include in risk assessment.

Risk estimation is projecting frequency and severity, the same tasks others include in risk analysis. This diagram infers quantitative risk estimation using probabilities to estimate the likelihood of a hazardous event. It seeks to place values on the severity.

Figure 34-2 also includes risk evaluation. In other models dealing with risk, the tasks under risk evaluation are part of risk management. Risk evaluation includes risk aversion and risk acceptance. Risk aversion is estimating how well one can reduce or avoid risks through various alternatives. Risk acceptance involves creating decision

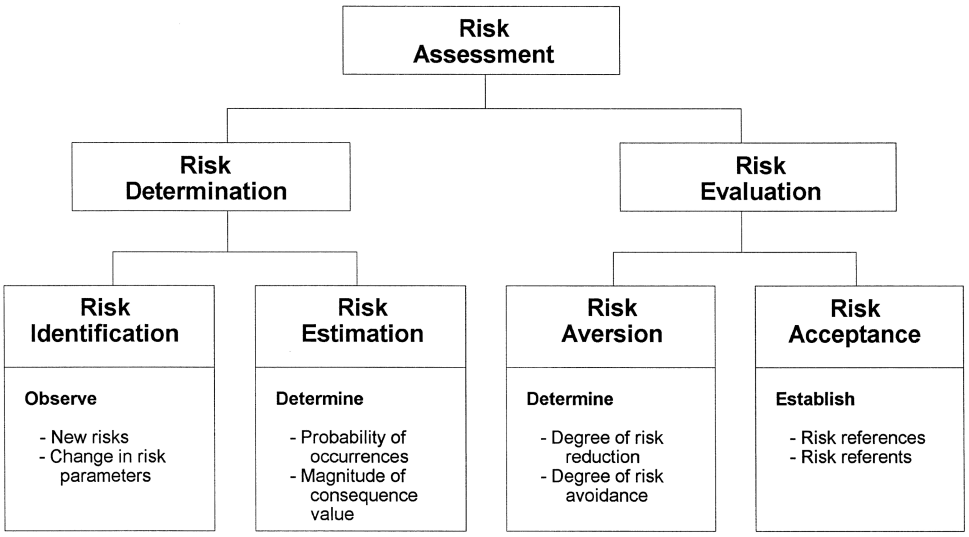


Figure 34-2. Risk assessment concept. (Derived from W. D. Rowe, *An Anatomy of Risk*, Wiley, New York, 1977.)

tables or standards for deciding what risks are acceptable for individuals, companies, or society. What is acceptable may differ for each group.

Chemical Risk Assessment

Chemical risk assessment has established a variation of these processes. The National Academy of Sciences[15] identified a four-step, chemical risk assessment procedure.

1. Hazard identification.
2. Dose-response assessment.
3. Exposure assessment.
4. Risk characterization.

Hazard Identification Earlier discussion covered hazard identification and some methods for it. Hazard identification may include engineering failure assessment, which consists of evaluating the reliability of specific segments of a plant operation and determining probabilistic results. Fault-tree analysis (see Chapter 36) is a common form of engineering failure assessment.

Dose-Response Assessment For chemicals, dose-response assessment involves describing the quantitative relationship between the amount of exposure and the extent of toxic injury or disease. It requires recognizing the hazard of a material before assessing the effects. A dose-response assessment may provide linear equations relating exposure or dose to response or disease. The equations may result from regression analysis of dose-response data or other statistical procedures.

Exposure Assessment Exposure assessment is describing the nature and size of the populations exposed to an agent and the magnitude and duration of the exposures. Exposures include past, present, and future exposures. Exposure assessment may include analysis of toxicants in air, water or food. It could apply also to the prevalence of certain factors in automobile accidents.

Risk Characterization Risk characterization is the integration of data and analysis to determine if people will experience effects of exposure. Risk characterization includes estimating uncertainties associated with the entire process of risk assessment.

Application Issues

Risk assessment must often rely on inadequate scientific information or the lack of data. For example, repair data may help to accurately predicting failures for newly designed equipment. The repair data may help fill a lack of understanding of phenomena involved in potential failures for the new equipment. In toxicological assessment, people must make assumptions about the validity of using animal studies to predict effects for humans. The assumptions may not be accurate without data from actual human exposure.

Some people involved in risk assessment will take a conservative approach to avoid overestimating risk. Others will use comparison techniques for various options. Then relative differences among options become more important than absolute estimates for individual options.

34-4 RISK MANAGEMENT

As noted, some models differentiate risk management from risk assessment. Risk management addresses what to do about the collection of risks derived during risk assessment. Risk management considers the relative significance of each risk and the associated consequences. It will develop strategies for eliminating risks, reducing their consequences or deciding how to manage them.

In some models, risk assessment is a part of the broad concept of risk management. From an insurance perspective, risk assessment is necessary to determine whether to insure a property, product or event. For other organizations, separating the two elements may make sense.

The insurance industry has organizations devoted to risk management. They offer their model as a way to explain the risk management processes. Some organizations have positions devoted to risk management. For example, hospitals and medical facilities often have risk managers who oversee risk assessment and management from a broad perspective for the entire organization.

Enterprise Risk Management

Some organizations use the term enterprise risk management to emphasize the wide array of risks they must recognize and manage. The organizations may have a complex set of activities. A way to create a standardized approach is to apply risk analysis and risk management to widely different functions within the organization.

RIMS, the Risk Management Society, defines enterprise risk management as a strategic business discipline that addresses a full spectrum of risks. It explains the broader perspective compared to risk management in several ways:

- Covers all types of risk exposures (financial, operational, reporting, compliance, governance, strategic, reputational).
- Prioritizes and manages exposures as a comprehensive group, not individual clusters.
- Evaluates the collection of risk in broad terms.

- Recognizes interrelationships among individual risks across an organization using combined exposures.
- Provides a structured process for the management of all risks.
- Views effective management of risk as a competitive advantage.
- Seeks to embed risk management as a component in all critical decisions throughout the organization.

An example of application of enterprise risk management is the University of California. It is a complex organization with several campuses scattered across the state. Each campus has a wide range of educational and support functions. It adopted enterprise risk management as a comprehensive and consistent way to manage risks across the entire organization. The Office of the President establish procedures, tools, and resources to assist units of the organization implement the concept.[16]

A Risk Management Process

The following discussion derives from an insurance viewpoint.

The Process

Risk management as a process involves five components:

1. Risk identification.
2. Risk analysis.
3. Eliminating or reducing risks.
4. Financing risks.
5. Administering the risk management process.

There are two groups of risk management objectives. There are pre-loss objectives that address what may happen. There are post-loss objectives that apply resources to completely and quickly recover from a loss. Table 34-3 defines pre-loss and post-loss objectives.

TABLE 34-3 Risk Management Objectives[a]

PRELOSS OBJECTIVES	
Economy	Minimizing the economic expenditures consistent with postloss goals for safety programs, risk identification and analysis, insurance premiums and so forth.
Reduction in Anxiety	Reducing the fear and worry over potential losses.
Meeting Externally Imposed Obligations	Satisfying safety, health and environmental regulations; satisfying employee-benefit plans; acquiring required insurance.
Social Responsibility	Meeting the demands for good citizenship to employees, customers, suppliers and the community. Maintaining public image and social consciousness
POSTLOSS OBJECTIVES	
Survival	Being able to resume some operations following a loss.
Continuity of Operations	To return to or continue full operations following an interruption. There may be reduction in earnings. Keeping human and material resources available.
Earnings Stability	Keeping earnings stable through continued operations with cost control or from funds to replace lost earnings.
Continued Growth	Finding ways to expand growth by product development, market expansion, acquisition and mergers.
Social Responsibility	Taking care of employees, customers, suppliers and the public. Maintaining public relations and public image

[a]Derived from R. I. Mehr and R. A. Hedges, *Risk Management: Concepts and Applications*, Richard D. Irwin, Homewood, IL, 1974.

Risk Identification

Risk identification is not an easy task. It is easy to overlook something. It requires training and experience to see unsafe conditions and foresee unsafe acts. It is not easy to see how combinations of events and the complexity of operations, equipment, and facilities can lead to undesirable events. As noted, participants in risk identification should expand the breadth of knowledge and experience in the task.

The goal in risk identification is to reduce uncertainty in describing factors that contribute to accidents, injuries, illnesses and death. Risk identification involves identification of hazards. It improves understanding of risks for particular situations or groups. One reason for risk identification is to determine whether effects in one situation will apply to another. Also, if they do, the task is to identify the extent of the relationships. Risk identification involves gathering facts and data. Participants in risk identification will analyze data to determine what components contribute to a process that produces injury or illness. They seek to establish if they can use data from particular cases to generalized to other situations or populations.

For example, can data from commercial airplane crashes in one year apply to the risk of death from flying for all commercial passengers in the future? Is it more accurate to characterize the risk for passengers by aircraft model, since an aircraft has undergone a major overhaul of an engine or airframe, or by the number of takeoffs and landings an aircraft has experienced? Similarly, in assessing the risks of chemicals, one must generalize data from

animal and organism studies to humans. Also, one must characterize the behavior of a chemical within the body. One must consider interactions with other substances in the body or interactions within cells and organs. A goal in risk identification is deciding on relevance of data sources.

Risks change with time. The process of identifying risks requires a continual and systematic approach. Risk identification involves recognition of hazards and what can go wrong. It may involve attaching values to potential losses. The values in this step help establish how certain a loss is for general situations. A risk may change over time.

There are many techniques for identifying risks. Hazard recognition is an important element. One approach is drawing on the past knowledge and history of accidents. Another approach is applying systematic techniques, such as system safety and other analytical methods (see Chapters 36 and 37). It may be necessary to use specialists and those with operational experience to help identify risks. Specialists have unique knowledge. Those with operational experience may recognize some important hazards that others overlook. Checklists of hazards and conditions producing hazards can help. They can provide comparisons with a proposed or actual operation, process, equipment item or system. Sometimes energy and energy release analyses help identify what failures may occur in a system and the potential consequences. Sometimes analysis of human behavior, training, experience, and underlying motivating factors helps identify risks.

Frequency and severity data from accidents can help identify risks. A review of accident records and classes of accidents can help. Various statistical methods applied to accident data can reveal trends in losses and factors that contribute to accidents and injuries. Analyzing claims, such as worker compensation claims[17] or customer claims against products, will help isolate factors associated with losses.

Risk Analysis

Risk analysis is applying qualitative or quantitative techniques to potential risks. It reduces the uncertainties in measuring risks. It usually involves frequency and severity. Frequency deals with the likelihood that an event will occur or that a hazard will be present. Severity is the effect of an event when it occurs. Severity has measures of deaths, injuries, disease, or illnesses or loss of equipment or property. Severity may have financial measures.

Example 34-1 Risk identification for an employer noted that people traveling in automobiles to and from work face the risk of vehicle accidents. Suppose the data show there are 29,800,000 automobile accidents per year in the United States, people travel 1.511 billion miles per year by automobile and the average person travels 4,500 miles each year driving to and from work. Risk analysis would identify the probability of an accident P from

$$P = 2.98 \times 10^7 (4500)/1.511 \times 10^{12}$$
$$= 0.089 \text{ accidents per year per person}$$

In time units, this would represent about one accident every eleven years per person.

It is not possible to quantify all risks. In many cases, qualitative risk analysis is the best available. One can use a classification scheme such as that shown in Figure 34-1. Table 34-4 and Table 34-5 provide a similar scheme. An analyst assigns one of five probability categories from Table 34-4 and one of four severity categories from Table 34-5. This scheme leaves out quantities completely. Analysts need considerable judgment to apply the categories consistently.

TABLE 34-4 Hazard Probability Classification

Description[b]	Level	Specific Individual Item	Fleet[a] or Inventory
Frequent	A	Likely to occur frequently	Continuously experienced
Probable	B	Will occur several times in the life of an item	Will occur frequently
Occasional	C	Likely to occur sometime in the life of an item	Will occur several times
Remote	D	Unlikely but possible to occur in the life of an item	Unlikely but can reasonably be expected to occur
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced	Unlikely to occur, but possible

[a]The size of the fleet or inventory should be defined.
[b]Definitions of descriptive words may have to be modified based on quantity involved.

Eliminating or Reducing Risks

After identifying and analyzing risks, one can attempt to eliminate them. However, it is not possible to eliminate all risks. Risk reduction is the only possibility for some risks. For others even risk reduction is not possible. One can only apply procedures to manage them.

TABLE 34-5 Hazard Severity Classification

Description	Category	Mishap Definition
Catastrophic	I	Death or system loss
Critical	II	Severe injury, severe occupational illness or major system damage
Marginal	III	Minor injury, minor occupational illness or minor system damage
Negligible	IV	Less than minor injury, occupational illness or system damage

TABLE 34-6 Example Classification for Costs to Correct Risks

Category	Value
A	< $1,000
B	$1,000–10,000
C	$ 10,000–100,000
D	> $100,000

When many risks exist at once or when there are only limited resources, the problem is deciding which risks to tackle first. This problem requires setting priorities. In most cases, the challenge is eliminating or reducing high severity risks first.

There are several methods for setting priorities. Cost-benefit analysis (see Chapter 35) is one possible financial method for making decisions. Example 34-2 gives a simplified case using a return-on-investment method. Chapters 36 and 37 will considered other methods. One can apply quantitative or qualitative methods when setting priorities. Regardless of the methods used to make decisions about eliminating or reducing risks, there is a need for some logical decision strategy. Two key decision factors for any method are the cost of implementing corrective actions and the degree of elimination or reduction achieved by actions.

Some methods add a classification table for grouping the correction costs. Table 34-6 gives an example of a cost-to-correct table. The preferred decisions and actions normally address those risks with high probability and severity and low cost to correct.

Financing Risks

Managing risks requires money to pay for risk management activities, including eliminating and reducing risks. An organization may establish a budget for risk management activities. There may be specific projects that flow from risk analysis and risk reduction. One can allocate funds from the authorized budget to individual projects, particularly to the most effective reduction alternatives. For high severity and low probability risks, an organization may want to develop a reserve fund as a financial strategy. Another financial option is purchasing insurance for certain risks. This transfers the risk to the insurance company. The premiums may be lower than the cost to implement a risk-reducing project. A third financial option is to spend nothing, taking a chance that a risk event will not occur. That may make sense for events that have low severity and low probability.

Example 34-2 The data from Example 34-1 can extend to financial considerations. Assume that the cost of vehicle accidents is $39.3 billion per year. The average cost per accident C is

$$C = \$39.3 \times 10^9 / 2.98 \times 10^7 = \$1,319 \text{ per accident}$$

Similarly, the financial risk for each person per year R is

$$R = 0.089 \times \$1,319 = \$117.39 \text{ per person per year}$$

From these data an organization can decide if it is financially better to buy insurance or create a fund to cover the cost of accidents. (In reality, most states require drivers to carry insurance.) In addition, other information may help to decide if there is any way to reduce the likelihood of an accident or reduce severity if one occurs. Alternatives may reduce the risk. For example, an organization could spend money for driver training, to have people drive larger cars that have lower cost per accident, or to make sure vehicles have protective features to reduce severity.

Administering the Process

The final step in risk management is administering the process. Part of administration is setting acceptable levels of risk. A company or organization must decide what level of risk it will assume and what level it will transfer.

Another aspect of administration is assigning resources to the process. The process may require specialists for risk identification and analysis. It may require financial specialists to help determine the overall costs and benefits and the most economical ways to finance risks.

Administering the process requires monitoring and evaluating. Someone must ensure that organizational units apply the process. Someone must measure results to find out if the organization achieved risk reductions and if projects reduced frequency and severity. Someone must measure the benefits obtained through the risk management process. Someone must select the methods used and train people to use them effectively.

Figure 34-3 is an example of a form for tracking risk identification, analysis and actions taken. Today the data on the form can be part of a computer-based risk management system. Although not very common, Figure 34-4 gives an example of a nomogram for analyzing risks and justify costs. The graphic simplifies decision making. A user finds data locations on some scales and connects the dots. The resulting lines help lead to decisions. Today, software algorithms can perform the functions of the nomogram.

34-5 EXAMPLES OF RISK-BASED METHODS

People have applied risk assessment and management in various ways. This section will take a closer look at a few specific approaches.

RISK MANAGEMENT DATA SHEET	
Item or Event	
Risk Identifier	**Method(s) Used**
Risk Ratings Frequency: _____ Severity: _____	
Description and Contributing Factors	
Summary of Supporting Data	
Corrective Action(s) Proposed	
Proposed Action	Effectiveness/Cost

Figure 34-3. Example of a risk management data sheet.

William Fine

Fine[18] proposed a method for deciding if there is justification for the cost to correct a hazard and how quickly to correct hazards. His method involves the use of risk. The approach provides a simple, orderly way to evaluate and compare a variety of hazards and controls and present them to management for approval.

The method begins by computing a risk score, R, from

$$R = C \times E \times P \tag{34-1}$$

where

C is the consequence rating value
E is the exposure value
P is the probability value

Then one uses the risk score to decide how quickly to act to correct the hazard. See Table 34-7 for decision guidance. One can compute a cost justification value, J, from

$$J = R/(\text{CF} \times \text{DC}) \tag{34-2}$$

where

CF is a cost factor

DC is a degree of correction value

One selects the values for Equations (34-1) and (34-2) from tables (see Table 34-7). Fine suggested that if $J > 10$, there is justification for the cost. If $J < 10$, there is no justification for the cost. Fine emphasizes that his method is useful for *guidance* only.

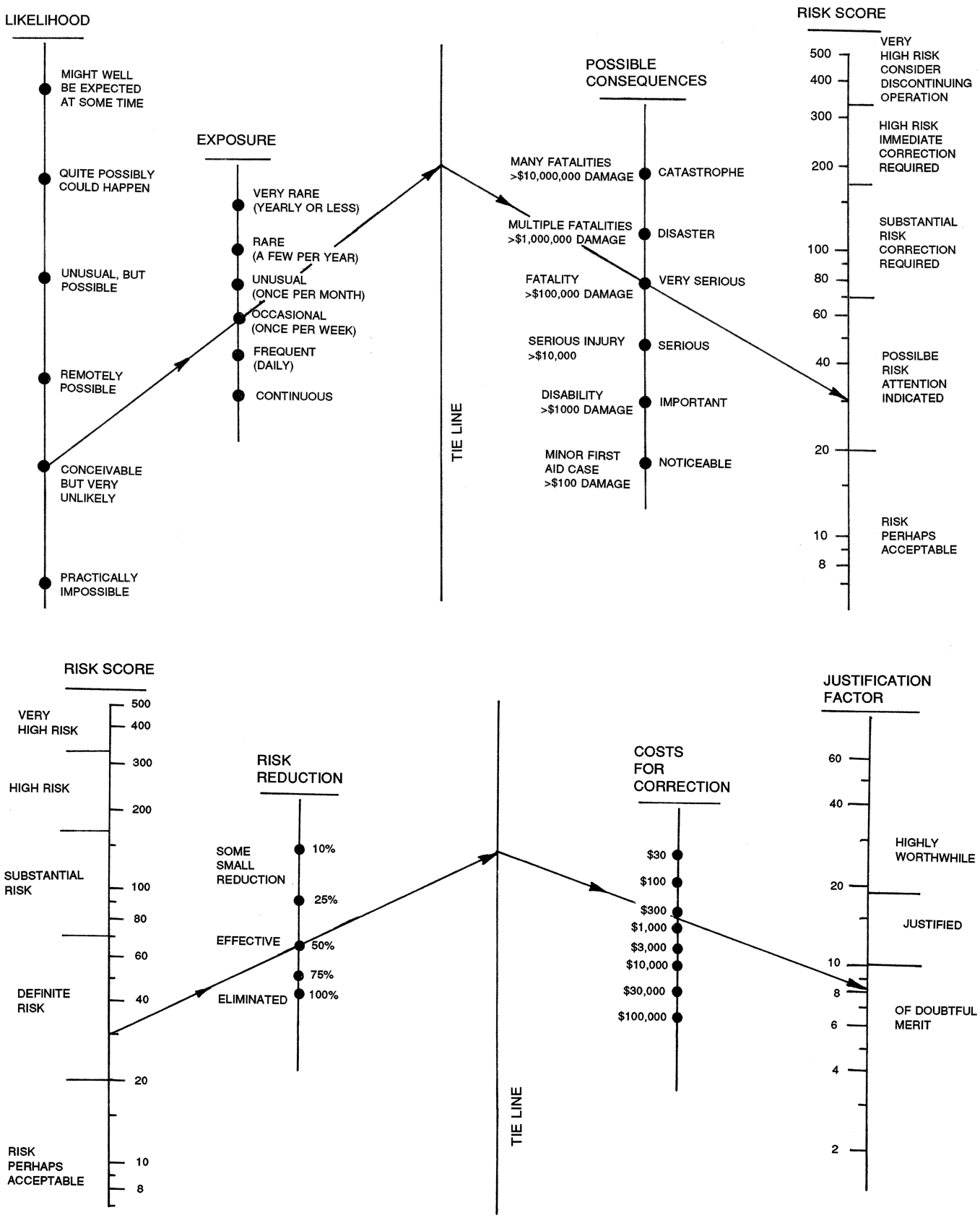


Figure 34-4. Nomographs for analyzing risk and cost justification. The procedure starts in the first chart by characterizing the likelihood of an event followed by the consequences that leads to a risk score. In the second chart, risk reduction and cost for correction move from the risk score to a justification factor for the risk reduction strategy. (From G. F. Kinney and A. D. Wiruth, *Practical Risk Analysis for Safety Management*. NWC Technical Publication 5865, Naval Weapons Center, China Lake, CA, 1976.)

TABLE 34-7 Values for Fine's Decision Process

CONSEQUENCES, C (Most probable result of potential accident)	
Rating	Classification
100	Catastrophe; numerous fatalities; damage over $1,000,000; major disruption of activities
50	Multiple fatalities; damage $400,000–1,000,000
25	Fatality; damage $100,000–400,000
15	Extremely serious injury (i.e., amputation, permanent disability; damage $1,000–100,000)
5	Disabling injury; damage up to $1,000
1	Minor injury or damage
EXPOSURE, E (Frequency of occurrence of the hazard event)	Hazard event occurs
10	Continuously (or many times daily)
6	Frequently (about once daily)
3	Occasionally (once per week to once per month)
2	Unusually (once per month to once per year)
1	Rarely (it has been known to occur)
0.5	Remotely possible (not known to have occurred)
PROBABILITY, P (likelihood that accident sequence will follow to completion)	Complete accident sequence:
10	Is the most likely and expected result if the hazard event takes place
6	Is quite possible, not unusual, has an even 50–50 chance
3	Would be an unusual sequence or coincidence
0.5	Has never happened after many years of exposure, but is conceivably possible
0.1	Practically impossible sequence(has never happened)
COST FACTOR, CF (Estimated dollar cost of proposed corrective action)	
10	> $50,000
6	$25,000–50,000
4	$10,000–25,000
3	$l,000–10,000
2	$100–1,000
DEGREE OF CORRECTION, DC (Degree to which hazard will be reduced)	
1	Hazard positively eliminated 100%
2	Hazard reduced at least 75%
3	Hazard reduced by 50–75%
4	Hazard reduced by 25–50%
6	Slight effect on hazard (< 25%)
RISK SCORE SUMMARY AND ACTIONS	
Score	Action
200–1,500	Immediate correction required. Activity should be discontinued until hazard is reduced
90–199	Urgent. Requires attention as soon as possible
0–89	Hazard should be eliminated without delay, but situation is not an emergency

The values used in the process and for decision making are somewhat arbitrary. When applying the method, a user can substitute other values in the tables and assign different values for J when making decisions.

Logical Process Risk Analysis

Frank and Morgan[19] proposed a systematic method for helping managers allocate funds to achieve the greatest risk reduction across several departments within a plant. The method is also useful to compare several plants and allocate funds to each. The procedure applies risk concepts. The authors developed the method for chemical processing plants. The method involves six steps:

1. Compute a risk index for each department.
2. Determine relative risk for each department.
3. Compute the percentage risk index for each department.

4. Determine composite exposure dollars for each department.
5. Compute a composite risk for each department.
6. Rank all departments relative to each other based on composite scores.

Risk Index One can develop a risk index for a department by evaluating hazards and controls. The risk index results from establishing a hazard score and a control score and then subtracting the hazard score from the control score. The authors developed a hazard checklist (see Table 34-8) and a control checklist (see Table 34-9). The hazard checklist includes six groups of hazards. It has points associated with each hazard within a group. The control checklist also has six categories with individual controls and points within each category.

The procedure first develops a hazard score for each department. In the procedure, one sums the points for those hazards that apply within a group. The procedure multiplies the sum within each group and a hazard or weighting factor for the group to achieve a score within the group. Then the procedure develops a hazard score for a department from the sum of scores computed for each of the six groups within the hazard checklist.

The procedure also develops a control score for each department in a similar manner. The first task is to identify what controls apply to a department within each of six groups of controls. Then one sums the points for each applicable control within a group and multiplies the sum and a group control factor for each group. Finally, the sum of scores for each of the six groups becomes the control score. The risk index is the control score minus the hazard score. A risk index may have a positive or negative value.

Relative Risk The goal is to rank departments, not individual hazards. The department with the highest risk index (highest positive value) is not likely to need much reduction in hazards. A high risk index value indicates that controls in place are effective. A department with a high risk index will not need funds as much as other departments. The authors use the best department risk score as the baseline or reference score for all other departments. The procedure adjusts all department scores relative to the score for the best department. The procedure subtracts the risk score for the best department from all other department risk scores. This adjustment makes the relative risk score for the best department zero.

Percentage Risk Index The percentage risk index for each department represents the relative contribution each makes toward the total risk of the plant. The procedure converts the relative risk for each department to a percentage of all risks using a simple procedure. The total risk for all departments is the sum of absolute values of all relative risk scores. Dividing the absolute value of the relative risk for each department by the total risk gives the percentage risk index.

Composite Exposure Dollars Next, one needs to know the total dollars at risk for each department, the composite exposure dollars. The composite exposure dollars are the sum of the monetary value of three components: property value, business interruption cost, and personnel exposure value. The procedure estimates the property value from the replacement cost of all material and equipment at risk in a department. Business interruption cost is the product of three elements. The three are: (1) unit cost of goods produced; (2) the department production capacity per year; and (3) the expected percentage of capacity. Personnel exposure value is the product of the total number of people in a department during the most populated shift and the monetary value for each person. The authors set the monetary value somewhat high to reflect that loss of life is not acceptable.

Composite Risk The composite risk, measured in dollars, for a department is the product of the composite exposure dollars and the percentage risk index. The composite risk represents the economic value of the relative risk for a department.

Final Ranking The final step in the process is to rank the departments based on composite risk. The goal of the procedure is to help managers decide where to apply funds to achieve the greatest risk reduction. Thus, rankings for departments range from highest composite score to lowest. The lowest will be zero for the reference department. The department with the highest composite risk score has the greatest risk reduction potential.

Example 34-3 Six departments in a plant seek money to improve process safety. The company elects to use logical process risk analysis as a guide for allocating funds. The goal is to reduce potential losses. The company completes analysis for each department to determine hazard scores, control scores and exposure dollars. Table 34-10 presents the data. The company ranks departments based on the data. Table 34-11 presents the results.

Risk Analysis with Return on Investment

Another example of risk analysis follows a process of computing risk and cost for controls. The final results give estimates of return on investment. The procedure will analyze processes, activities or equipment. The first step is hazard identification, followed by estimates of frequency and severity of losses for each hazard. There are one or more controls associated with each hazard. The procedure determines the

TABLE 34-8 Hazard Checklist

Rating Points	Hazard Group and Hazard (Group Hazard Factor shown in parentheses)
Fire/Explosion Potential (10)	
2	Large inventory of flammables
2	Flammables generally distributed in the department rather than localized
2	Flammables normally in vapor phase rather than liquid phase
2	Systems opened routinely, allowing flammable/air mix, versus a totally closed system
1	Flammables having low flash points and high sensitivities
1	Flammables heated and processed above flash point
Complexity of Process (8)	
2	Need for precise reactant addition and control
2	Considerable instrumentation requiring special operator understanding
2	Troubleshooting by supervisor rather than operator
1	Large number of operations and/or equipment monitored by one operator
1	Complex layout of equipment and many control stations
1	Difficult to start up or shut down operations
1	Many critical operations to be maintained
Stability of Process (7)	
3	Severity of uncontrolled situation
2	Materials that are sensitive to air, shock, heat, water or other natural contaminants in the process
2	Potential exists for uncontrolled reactions
1	Raw materials and finished goods that require special storage attention
1	Intermediates that are thermally unstable
1	Obnoxious gases present or stored under pressure
Operating Pressure Involved (6)	
3[a]	Process pressure in excess of 110 lb/in.^{2} (gauge), or
2[a]	Process pressure above atmosphere but less than 110 lb/in.^{2} (gauge), or
1[a]	Process pressure ranges from vacuum to atmospheric
3	Pressures are process rather than utility related
2	High pressure situations are in operator frequented areas
1	Excessive sight glass application
1	Nonmetallic materials of construction in pressure service
Personnel/Environmental Hazard Potential (4)	
3	Exposure to process materials pose high potential for severe burns or severe health risks
2	Process materials corrosive to equipment
2	Potential for excursion above TLV
1	Spills and/or fumes have high impact on equipment, people or services
1	High noise levels make communication difficult
High Temperatures (2)	
1[a]	Equipment temperatures exist in < 100 °C range (low), or
2[a]	Equipment temperatures exist in 100 < 170 °C range
3[a]	Equipment temperatures exist in 170 < 230 °C range [350 lb/in.^{2} (gauge) steam]
2	High temperature situations are in operator-frequented area
2	Overflows and/or leaks are fairly common
2	Heat stress possibilities from nature of work or ambient air

[a]Maximum of 3 points from this subgroup.

cost of each control and estimates its effectiveness. Effectiveness is the reduction in frequency and severity of losses. The procedure assumes that implementing a control will reduce risk to some level in comparison to the level without the control. The net results of the procedure include benefits, return on investment and payback period for an investment.

Example 34-4 A company wants to reduce the hazards of injury in a machine. There are two options that may help: installing a guard or using an interlock device. The goal is to compare each approach and express the solution as a return on investment. Table 34-12 compares the two alternatives.

TABLE 34-9 Control Checklist

Rating	Control Group and Control Points (Group Control Factor shown in parentheses)
	Fire Protection (10)
4	Automatic sprinkler system capable of meeting demands
2	Supervisors and operators knowledgeable of installed fire protection systems and trained in proper response to fire
1	Adequate distribution of fire extinguishers
1	Fire protection system inspected and tested with regular frequency
1	Building and equipment provided with capability to isolate and control fire
1	Special fire detection and protection provided where indicated
	Electrical Integrity (8)
3	Electrical equipment installed to meet NEC area classification
1	Electrical switches labeled to identify equipment served
1	Integrity of installed electrical equipment maintained
1	Class I Division 2 installations provided with sealed devices. Explosion proof equipment provided or purged reliably and good electrical isolation between hazardous and nonhazardous areas.
1	All electrical equipment capable of being locked out
1	Disconnects provided, identified, inspected and tested regularly
1	Lighting securely installed and facilities properly grounded
	Safety Devices (7)
3	Relief devices provided and relieving is to a safe area
2	Confidence that interlocks and alarms are operable
2	Operating instructions are complete and current, and department has continuing training and/or retraining program
1	Safety devices are properly selected to match application
1	Critical safety devices identified and included in regular testing program
1	Fail-safe instrumentation provided
	Inerting and Dip Piping (5)
2	Vessels handling flammables provided with dip pipes
2	Vessels handling flammables provided with reliable "inerting" system
2	Effectiveness of inerting assured by regular inspection and testing
1	Inerting instruction provided and understood
1	Inerting system designed to cover routine and emergency startup
1	Equipment grounding visible and tested regularly
1	Friction hot spots identified and monitored
	Ventilation/Open Construction (4)
3	No flammables exist or open air construction is provided
2	Local ventilation provided to prevent unsafe levels of flammable, toxic or obnoxious vapors
2	Provision made for containing and controlling large spills and leaks of hazardous materials
1	Building design provides for natural ventilation to prevent accumulation of dangerous vapors
1	Sumps, pits, etc., nonexistent or else properly ventilated or monitored
1	Equipment entry prohibited until safe atmosphere assured
	Accessibility and/or Separation (2)
2	Critical shutdown devices and/or switches visible and accessible
2	Adjacent operations or services protected from exposure resulting from incident in concerned facility
2	Operating personnel protected from hazards by location
1	Orderly spacing of equipment and materials within the concerned facility
1	Adjacent operations offer no hazard or exposure
1	Hazardous operations within facility well isolated

Chemical Risk Analysis

Although the steps in the risk assessment process seem quite simple, the procedures for applying risk assessment to chemicals becomes complicated. There are many points in the process requiring technical judgment. As a result, considerable knowledge and experience with the process are necessary to understand the many intricacies involved. The methods include many quantitative elements.[20]

Hazard recognition is a starting point in applying risk assessment to hazardous chemicals. The process depends on data from toxicological studies. The amount and type of data vary widely for different chemicals.

There are several difficulties in estimating chemical hazards. For example, animal studies may have used single doses. As a result, there is little information for estimating chronic exposure problems. Also, animals may have had high dose rates that are not representative of human exposures. Overall, there are difficulties in extrapolating animal data to humans. Although most human carcinogens are also animal carcinogens, the converse is not necessarily true.

Additional difficulties arise when making dose–response assessments. First, one must select what measure of dose to use. A common measure is milligrams of chemical per kilogram of body weight per day. Then there is application of a scaling factor between species. Procedures make an adjustment for absorption rates, because several factors affect absorption. Also, there is an extrapolation from high to low doses. Not all extrapolations are linear or linear over a range of dose rates. There may be a need also to make an adjustment for threshold effects. For some substances, there are no-observable-effect levels (NOELs) or lowest-observed-effect levels (LOELs).

The assessment of exposure also has complicating factors. First, researchers must consider the medium of exposure, such as air, diet, water, or soil. Then there is a need to account for the duration of exposure. An exposure may be chronic, covering a major portion of a lifetime, or acute, involving one contact or contact for one day or less. Exposures between acute and chronic have the name subchronic. Researchers must know what concentration is in an

TABLE 34-10 Data for Example 34-3

Exposure Dept	Hazard Score	Control Score	Property Value ($ × 1000)	Business Interruption Cost ($ × 1000)	Personnel Value ($ × 1000)	Composite Exposure Dollars
A	257	304	2900	1400	900	5200
B	71	239	890	1200	653	2743
C	181	180	1700	720	1610	4030
D	152	156	290	418	642	1350
E	156	142	520	890	460	1870
F	113	336	2910	3100	1860	7870

TABLE 34-11 Results of Analysis for Example 34-3, Including Final Ranking for Departments

Dept.	Risk Index	Relative Risk	% Risk Index	Composite Exposure ($ × 1000)	Composite Dollars Risk ($ × l000)	Rank
A	47	−176	−22.3	5200	1160	1
B	168	55	7.0	2743	192	4
C	−l	−224	28.4	4030	1145	2
D	126	−97	12.3	1350	166	5
E	−14	−237	30.0	1870	561	3
F	223	0	0.0	7870	0	6
		−789	100.0			

environment and must estimate the intake rate for a particular environment. Some common units for doses in exposure assessment are maximum daily dose (MDD) and lifetime average daily dose (LADD). The measures frequently find use in carcinogenic risk assessment. LADD estimates come from the product of the average MDD and the fraction of the total life span of an exposure (exposure days per days in a lifetime). Researchers also need characteristics of exposed individuals. Factors such as age, gender, health status, and other exposures (such as cigarette smoke, occupational agents, etc.) may contribute to the risk.

Finally, researchers calculate a risk estimate from all the other data and analyses. There are various ways to report risk. One method is establishing allowable dose rates for humans. Typical units are acceptable daily intake (ADI), which derive from NOELs. Risk estimates may include a safety factor to protect sensitive people. If there are data from human studies, the safety factor is smaller compared to having data available from animal studies only.

Risk assessment for chemicals is a complicated process of generalizing risk from known, highly controlled situations

TABLE 34-12 Risk Analysis for Example 34-4

Step in Analysis	Option A	Option B
A Hazard: Getting caught in a machine		
B Frequency of occurrence (events per year)	3	3
C Severity (expected $ loss per event)	$10,000	$10,000
D Risk, annual (B × C)	$30,000	$30,000
E. Control	Guard	Interlock
F Control cost (initial, assume no annual recurring costs)	$2000	$800
G Control effectiveness (relative to B)	90%	70%
H. Control effectiveness (relative to C)	80%	80%
I Risk after control is implemented (B × G)(C × H)	$21,600	$16,800
J Benefit, annual (D - I - F)	$6,400	$12,400
K Return on investment (100 × J/F)	320%	1550%
L Payback period, years (F/J)	4 months	3–4 weeks

to situations that were not part of the studies. Regardless of its difficulties and uncertainties, risk assessment is a systematic way to organize, analyze and present information on environmental chemicals and to decide when there is a need for public protection.

For risks in chemical processes, readers should refer to detailed procedure that go beyond the scope of this book. The bibliographies for this chapter and for Chapter 35 contain several references.

EXERCISES

1. A company developed data on injuries based on getting caught in machines. The data show that on the average 15 workers in company machine shops receive a machine injury each year. The measured severity in financial terms found that the average cost per case is $9,750. lf there are 450 machine shop workers in the company, what is the risk (cost per year) for each worker?
2. A company is contemplating changing a process to reduce a hazard. The company has the following data about the change:
   - If there is an accident, there will be multiple fatalities and over $500,000 in damage.
   - The hazard event occurs once per year.
   - There is a small chance (coincidental) that an accident sequence will follow to completion.
   - The cost to correct the hazard is $60,000. The correction will reduce the hazard by 80%. Use the William Fine method to determine:
     - Risk score and a recommended action to correct the hazard
     - Cost justification and a decision to implement the change.
3. Use the logical process risk analysis method to determine the ranking for applying funds to each of five plants in a company. Several plants were part of the analysis. The following table lists data for the five plants under current consideration.

Plant	Relative Risk (%)	Composite Exposure ($)
A	8	822,000
B	15	1,219,000
C	16	759,000
D	7	598,000
E	21	1,021,000

REVIEW QUESTIONS

1. Define the following:
   - **(a)** risk
   - **(b)** risk aversion
   - **(c)** loss control
   - **(d)** risk management
   - **(e)** risk assessment
   - **(f)** risk analysis
   - **(g)** loss control
   - **(h)** Lord Robens Report
   - **(i)** duty of care
   - **(j)** precautionary principle
   - **(k)** Type I policy error
   - **(l)** Type II policy error
   - **(m)** coupling
   - **(n)** tight coupling
   - **(o)** loose coupling
   - **(p)** Risk Perception Factor
   - **(q)** NOEL
   - **(r)** LOEL
   - **(s)** MDD
   - **(t)** LADD
   - **(u)** chronic exposure
   - **(v)** acute exposure
   - **(w)** subchronic exposure
   - **(x)** ADI
2. What are the five steps in risk management? Briefly explain each.
3. What are the four steps in risk assessment? Briefly explain each.
4. Discuss some problems in each of the four steps of risk assessment when it is applied to chemical risks.
5. To what is Fine's risk method applied?
6. To what is logical process risk analysis applied?

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CHAPTER 35

SAFETY MANAGEMENT

35-1 INTRODUCTION

A safety director for a major steel manufacturing and construction company was describing safety practices during construction of large bridges. He stated, "When I walk onto a construction site, I can tell the quality of the company's management process and its safety management by observing the organization of materials at the site." His observations told him whether an organization managed details, including safety. An organization that manages the details of its business is more likely to be successful than an organization that gives little attention to them.

There are many stories one could cite that demonstrate the importance management plays in making products and operations safe. As noted early in this book, there are many people who have important roles in safety. Engineers and others who identify hazards and needed controls must work with management to achieve safety. Implementing safety in an organization requires participation from everyone, from the top of an organization to the bottom. Achieving safety requires orderly processes for safety that are integral with management of other aspects of the business.

35-2 ELEMENTS OF MANAGEMENT

What is management? What do managers do? What are the elements of management? The many books and writings on management provide countless definitions of management and what management entails. The aim here is to create a general understanding of management that will provide a framework for addressing how safety can be a part of an organization's management processes.

Chapter 9 proposed a Goal Accomplishment Model (Figure 9-4) to help identify hazards and controls. The model assumed that organizations have goals to be accomplished. There are several elements that contribute to accomplishing the goals:

- *Activities:* Knowing what must be done and doing it correctly and safely.
- *People:* Having the right number of workers and skills for the activities.
- *Equipment and materials:* Having the right tools, machines, process equipment, and raw materials to complete the activities and produce the output.
- *Facilities:* Having the buildings and systems necessary to make the activities productive.
- *Physical environment:* Keeping the workplace and its surround conducive to effective work, healthy workers, and a safe community.
- *Social and management environment:* Providing the leadership, communication, and motivation for people to work effectively together.
- *Regulations:* Having policies, methods, and procedures in place for things to be orderly and safe.
- *Time:* Having enough time or organizing time to complete the activities.
- *Cost:* Having enough funds to provide the preceding elements necessary to accomplish the organization's goals.

Management involves planning, obtaining, organizing, and orchestrating the elements necessary to achieve the goals.

Grose[1] characterizes the three main elements of management as three legs of a stool. The three elements are performance, cost and schedule. Performance denotes having defined tasks. Cost include funds and manpower for the tasks. Schedule involves organizing tasks into a sequence and assigning completion dates. The three-legged stool of management reflects a model quite suitable for management of projects.

Grimaldi and Simonds[2] identify three steps in an orderly pursuit of an objective. The three steps are organizing, administrating, and managing. Organizing is the structuring of authority and activity relationships and using resources at hand to meet a group's objectives. It includes the arrangement of subtasks into a coordinated effort. Administrating is carrying out the tasks of planning, organizing, coordinating and measuring performance that move an organization toward its goals. Managing, although similar, adds the dimension of leadership. Leadership sets the tone for

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CASE 35-1

35-1a

January 28, 1986, Cape Canaveral, FL. The O-ring seal in the booster rocket eroded and blow-by burned a hole in the external fuel tank. Suddenly, mission 51-L exploded before a world-wide audience on live television. The screens in the control room went blank; only a white S remained at the top of each mission control monitor screen. Seventy seconds after launch the Challenger space shuttle fell in pieces from 50,000 ft to the ocean below.[a]

35-1b

October 1986. The Presidential Commission on the Space Shuttle Challenger Accident (the Rogers Commission) presented its findings. Chapter 7, entitled "The Silent Safety Program," states[b]:

1. Reductions in the safety, reliability and quality assurance work force at Marshall and NASA Headquarters have seriously limited capability in those vital functions.
2. Organizational structures at Kennedy and Marshall have placed safety, reliability and quality assurance offices under the supervision of the very organizations and activities whose efforts they are to check.
3. Problem-reporting requirements are not concise and fail to get critical information to the proper levels of management.
4. Little or no trend analysis was performed on O-ring erosion and blow-by problems.
5. As the flight rate increased, the Marshall safety, reliability and quality assurance work force was decreasing, which adversely affected mission safety.
6. Five weeks after the 51-L accident, the criticality of the Solid Rocket Motor field joint was still not properly documented in the problem reporting system at Marshall.

Another author writes[c]:

> . . . the "press on" mentality had taken hold of NASA's management, and they were able to accept conditions that would have surely provoked the scrub of another launch . . . Rather than demanding that all those supporting the launch prove that conditions were safe, the senior members of the launch team demanded that their subordinates and the contractor representatives prove that it was *not* safe to launch Challenger.

[a] http://www.history.com/topics/challenger-disaster/videos/engineering-disasters—challenger

[b] http://history.nasa.gov/rogersrep/genindex.htm

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CASE 35-2

February 20, 2014, near Doctortown, GA. A freight train struck and killed Sarah Jones, a camera assistant, and injured seven others working to film for a scene in *Midnight Rider*, a biographical movie about a musician, Gregg Allman. The crew was on a narrow trestle bridge. A train belonging to the railroad line arrived, struck the set and killed the assistant. According to preliminary reports, the crew had received permission to occupy private land through which the railroad passed. It had not obtained permission from the railroad to be on the tracks. No one was observing for a potential arrival of a train around the curve leading through the woods to the bridge. The 2014 Academy Awards ceremony included recognition for Sarah Jones.

The death raised significant questions about safety practices during filming of Hollywood movies and other complex, temporary activities. While not all who create movies ignore safety considerations, the entertainment industry has compiled a history of notorious accident cases. A general challenge for those working in the entertainment industry and in temporary situations is placing safety above the push to get the show underway or the job done.

Several investigations followed the filming incident. Preliminary information reported in several trade and national publications provided some information about the incident.[a,b,c,d,e]

The case illustrates safety management issues for people working in remote situations and constantly changing job settings. Below are just a few questions to consider for such situations:

- Does planning for work in remote locations and changing work situations include written safety plans?
- Do safety plans include risk analysis to identify what can go wrong during the work activities and actions to prevent accidents?
- Do safety plans include identification of procedures for first aid, emergency management, medical and hospital access?
- Do plans address how to prevent potential dangers?
- If there are potential dangers, are people assigned as watchers to provide warnings and escape time for others?
- If there is a need for approval to film or work on someone's property, has the owner issued an approval? Has the owner identified safety standards and procedures for occupants to ensure protection for all involved including any owner's employees?
- Have those working in remote and changing situations received proper training to create a safety culture, in the details of safety plans for the specific activities, and to manage the specific remote activities safely?

[a]Scott Johnson, "A Train, a Narrow Trestle and 60 Seconds to Escape: How 'Midnight Rider' Victim Sarah Jones Lost Her Life," *The Hollywood Reporter*, March 4, 2014. www.hollywoodreporter.com/news/midnight-rider-accident-sarah-jones-death-gregg-allman-685976)

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[c]http://deadline.com/2015/09/midnight-rider-osha-ruling-sarah-jones-commission-statement-1201555335/

[d]http://www.sarahjonesfilmfoundation.org/

[e]http://safetyforsarah.com/

the tasks. It involves the use of facts and persuasiveness to strengthen authority and achieve the goals effectively.

Bittel and Ramsey[3] compiled material on 50 vital areas of concern to professional managers. They built the areas out of three basic ones:

- *Primary management functions:* planning, organizing, activating, controlling, and decision making.
- *Major business activities:* finance and accounting, operations and production, marketing and sales, and information management.
- *Environmental resources and constraints:* human resources, materials, funds, equipment and facilities, consumer demand, economic conditions, natural resources, community influences, and government regulations.

The management process assembles resources and converts them into output, such as products and services. At the same time, the process must work within multiple environments. Figure 35-1 illustrates one view of fundamentals of the management process.

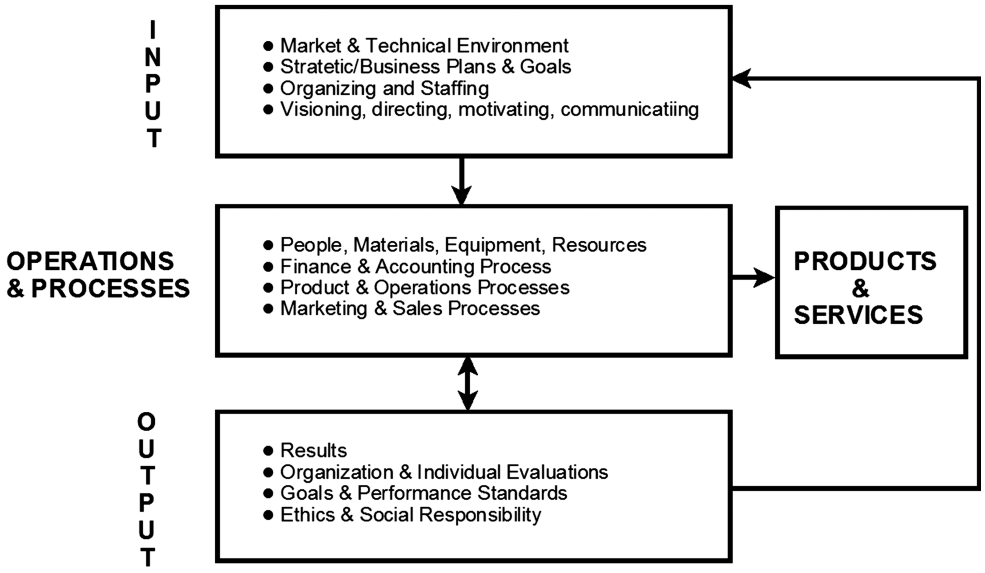


Figure 35-1. An overview of the management process.

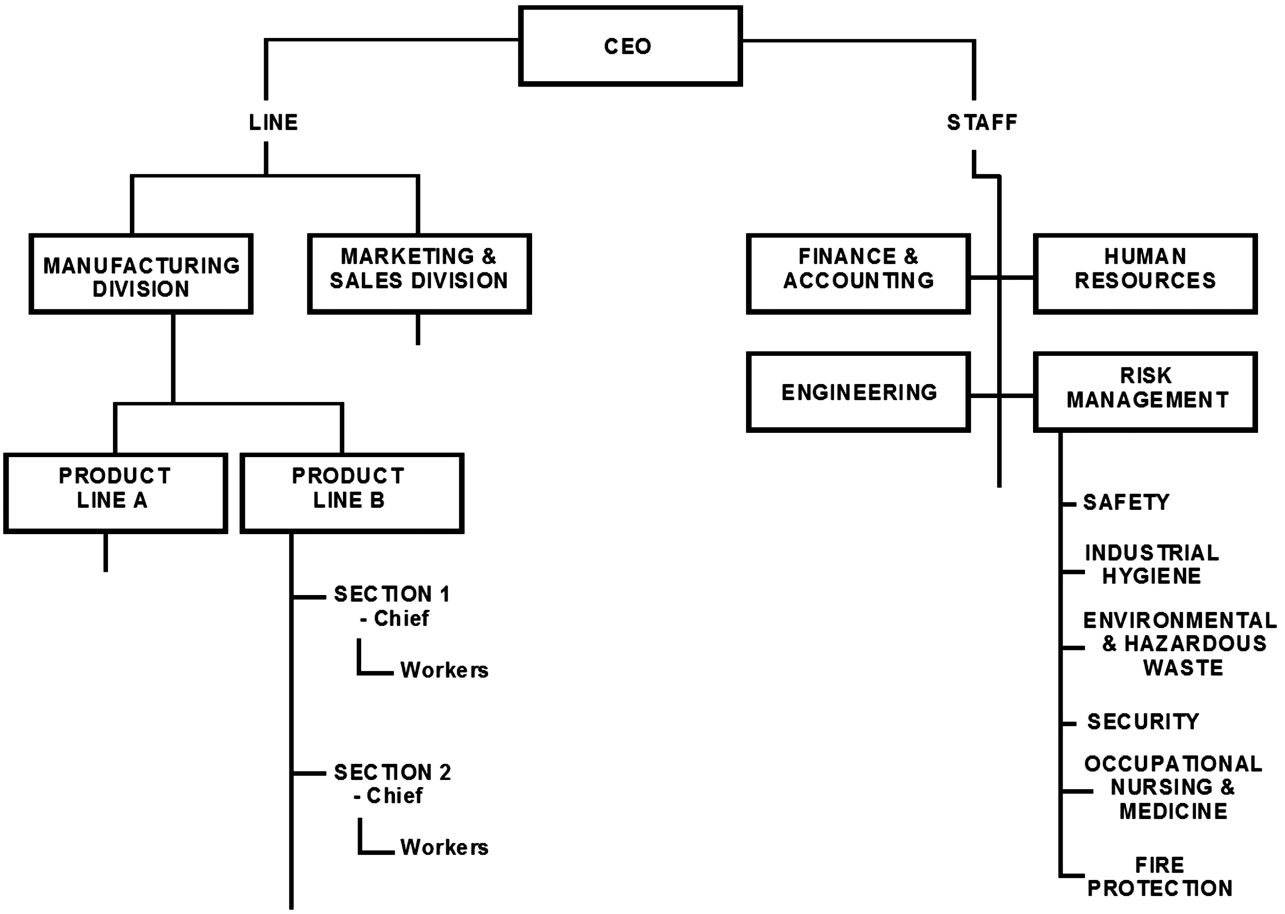


Figure 35-2. One example of the placement of safety, health and environmental functions within an organization.

Management is getting things done through other people. Management is performing those functions essential to the success of an organization. Safety is one of those functions.

35-3 POSITIONING SAFETY IN AN ORGANIZATION

As noted in Chapter 32, safety begins in an organization with a policy stating the importance of safety. It assigns responsibility, authority, and accountability. Extensions of the policy are procedures that detail implementation.

There are many ways to structure an organization to make it effective. As a result, there are many ways to assign safety responsibilities. Many organizations structure functions into two major components: line and staff. Line elements of an organization are those that produce a product or deliver a service. They get the detailed work done. Staff elements take care of business matters, such as finance, accounting, research and development, and sales. Staff elements also take care of special matters, such as legal, security, training, engineering, and maintenance. Most staff elements assist and facilitate getting the work done. However, they do not have authority over line organizational units. Figure 35-2 illustrates one organizational structure and shows possible locations for safety specialties.

Safety must be a part of every organizational element. Line elements must complete work safely. All workers need training for safe procedures. They need technical assistance of staff elements who have advance knowledge of safety. Each level of supervision or management in line elements must keep safety paramount. Otherwise, safety will lose its importance for levels below them. Safety must be part of leadership characteristics of every supervisor and manager. Some feel that first-line supervisors are the key to safe operations. They directly influence their workers and the tasks performed.

For larger organizations, the safety and health units in the staff structure may include several specialists. There may be specialists in safety, industrial hygiene, health physics, occupational medicine and nursing, and fire protection. Many organizations have consolidated safety, health, and environmental responsibilities into one organizational unit. Sometimes security is part of this unit. Sometimes insurance

and workers' compensation functions fall under risk management. In some cases, most or all of these specialties report to human resources or to a company vice president.

The ability of a line organization to handle safety effectively may have a relationship to its location in an organization. The Rogers Commission Report (Case 35-1b) provides an example of an organizational disconnect for a safety function.

A safety director or staff person responsible for safety must have the ear of top management. The safety director serves as the spokesman for top management in safety matters. Petersen[4] cites four criteria for positioning the staff safety element in an organization.

1. Report to a boss with influence.
2. Report to a boss who wants safety.
3. Have a channel to the top.
4. If possible, install safety under the executive in charge of the major activity.

For many smaller organizations, there is not a full-time safety professional on staff. The person with safety leadership responsibility also may have other job functions. Both full-time and part-time specialists should pursue training about hazards, controls, safety management, and legal and regulatory matters. A safety specialist should create access to necessary medical, engineering and others with specialized safety knowledge. An organization may need access to licensed or certified specialists.

35-4 ACHIEVING SAFETY IN AN ORGANIZATION

There are many theories and methods of management. Managers must apply various methods to situations they face. Chapter 31 introduced some management approaches. Some approaches work better than others for certain situations.

There are many factors that contribute to low accident rates in an organization. These factors also apply to achieving other company objectives. To be effective, safety must be an integral part of the management process. Effective leadership of organizational units should include a commitment to achieving safety. It should ensure that all workers return home at the end of each workday. The following discussion will consider several management factors that help achieve safety.

Management Style

Different people approach the tasks of management differently. Some are very authoritative, directing virtually every action of their people. Others encourage subordinates to participate in decision-making and setting the climate for getting the job done. Management style can affect results. Different styles may work better than others for some individuals or in some situations.

Earlier discussion identified the importance of safety policy, safe operating procedures, training on safe work practices, training for contingencies or unique situations, and use of methods, such as risk assessment. Managers and supervisors at all levels need training that links safety to organizational, leadership and performance skills. Managers and supervisors need to develop skills for gaining worker participation in safety achievement. Having managers at all levels who endorse safety is not enough. They need to develop ways to gain work group commitment for completing work safely. Organizational, management, or leadership style strongly influence safety performance. They require a focus on the details. The same skills lead to high production levels, teamwork, low error rates, and minimal rework. The same skills lead to quality in all aspects of a work group's role.

One study[5] analyzed the safety records of crews working under particular supervisors. The study found that those supervisors whose crews had a better safety record managed differently from those with poor records. The supervisors with good safety records also had high productivity. The successful supervisors controlled anger, kept stress from their crews, and maintained close contact with their workers. They also integrated safety into production tasks rather than simply admonishing workers to be safe.

Accountability

Making safety part of a supervisor's or manager's performance appraisal is one means of achieving safety in an organization. Researchers[6] found that top management can affect safety by knowing the safety records of field managers and using this knowledge for promotions and salary increases. Many companies derive the knowledge from an accounting system. The study found that companies using the following techniques had lower accident rates than companies that did not do the following:

- Use cost accounting to encourage safety of managers.
- Require managers to do detailed safety planning.
- Provide new employees with adequate training.

For accountability to work, there must be a way to count success or failure: There must be an accounting system. Many companies use a cost accounting system (discussed further in Section 35-5) for accidents. Managers must receive the cost data for it to have relevance for the department or organization. Other data may provide a way to organize the performance data. Examples are using severity, type of accident, and location. The additional breakdown may help the manager identify what to correct.

Other techniques for accountability are useful. A later section will discuss leading and trailing indicators for safety. Accident and incident data, for example, are types of trailing indicators. They provide delayed results and trail many important preventive activities. Leading indicators measure safety activities which occur independent of accidents and incidents. Regular tailgate talks for construction crews is one form of leading indicator.

Another approach is a safety-by-objectives method. It focuses on performance objectives that may link to pay or bonuses. For example, a manager may meet with a first line supervisor, steward or subordinate manager and discuss safety hazards or safety performance issues for the person's organizational unit. The meeting may involve others with knowledge or experience. The meeting product is a safety-by-objectives plan that seeks to reduce hazards or increase safety performance. Examples of objectives are certain employee training, improved work discipline, improved housekeeping, correcting specific hazards, or participating in safety development programs. The plan prioritizes particular objectives to address during a particular period. The approach focuses on improvement and prevention, not a safety record.

Paying Attention to Details

As noted in the opening of this chapter, effective safety performance requires paying attention to details. Focusing on details also leads to productivity. Managers and supervisors who make sure their work groups stay organized and do their jobs well will improve group performance overall and in safety. Planning and organizing work are part of success. Making sure everyone knows their responsibilities and how to complete tasks properly contribute to that success. Proper training and understanding about what can go wrong also help. Effective feedback and positive verbal support help achieve success.

One example of effective work planning is job safety analysis (JSA), described in Chapter 31. A manager or supervisor can engage experienced employees to help identify hazards that can arise in upcoming work. Those with experience can help newer employees anticipate and foresee what can go wrong and learn how to prevent or respond to such events. Engaging employees in safety of their work helps motivate them to perform well. Workers want to do a good job. They are sensitive to what their employers expect of them. In addition, managers and supervisors who encourage communications to their work groups from those higher in an organization will provide additional motivation. Such communications can help ensure that workers pay attention to details of their work.

Enforcement

Enforcement is not just having rules and someone to enforce them. Enforcement involves communication. It includes clearly explaining the need to do a job right and how to do it safely. Enforcement includes conveying a clear understanding of what an employer expects on the job. It includes motivating workers to achieve desired results and meeting goals for their work groups. Enforcement may use behavior-based safety to observe and offer feedback on performing job tasks correctly and safely.

Clearly, enforcement requires managers and supervisors to correct dangerous behavior and to improve operating procedures that are not clear and understandable. Failure to comply with safety policies and rules requires correction. However, positive feedback is more effective than negative feedback.

Leadership

Effective organizations thrive on strong leadership. Leadership is an essential part of achieving safety performance in an organization. There must be a commitment to safety from the top of an organization to the first line supervisors and workers. One way to gain that commitment is through effective safety leadership at all levels.

Safety leaders share their commitment to safety with those working for them. Safety leaders clearly and continually explain the importance of safety for their workers and guide them through the details necessary for safe work and workplaces. Safety leaders provide feedback on safe practices and correct unsafe practices. Safety leaders monitor work to assure that safety is a standard for their workgroups. Safety leaders continually learn how to improve safety performance of their workgroups and how to recognize the safety impact of their workgroups on the safety of other workgroups.

Safety leaders must learn safety leadership. Some people have certain leadership qualities and characteristics. Safety leadership is not an automatic part of such qualities. Safety leaders must know how to recognize hazards for the work they oversee and how to protect against those hazards. Safety leaders need to know how to communicate safety practices effectively and influence safety among their workers.

There are many sources of information and learning opportunities available to learn and improve leadership skills. A part of those should address increasing safety leadership for all supervisors and managers. Some organizations establish standards of achievement for safety leadership at all levels.

Performance

An old business adage is, "What gets measured gets attention." Traditionally, safety people used trailing indicators, metrics, or outcomes. Traditionally, the metrics included accident and incidents, lost time cases, injuries

and injury details, workers' compensation, near misses or other insurance claims, legal cases. There are sources of comparison data for employers from nationally compiled information. Through its Injury, Illness and Fatalities (IIF) program, the Bureau of Labor Statistics publishes annual reports[7] by industry, geographic location, and other factors. The National Safety Council has compiled accident and injury data for decades and reports results in a long-standing, annual publication, *Injury Facts*[8] (for many decades, known as *Accident Facts*). The Federal Highway Administration also compiles traffic accident data and publishes annual reports.[9] Many companies and employers compile similar information and produce annual reports.

Leading versus Trailing Safety Performance Indicators

More recently, safety people have applied leading, upstream, predictive, activity, preventive or process indicators or metrics to measure safety performance. This family of measures often includes safety audits, behavior-based safety measures, safety perception surveys, safety training, corrective actions completed, reductions in risk and risk factors, identifying safety and ergonomic opportunities, and other measures. Many use leading indicators[10] to do the following:

- anticipate, prevent or eliminate risks and losses;
- monitor and evaluate performance;
- motivate safe behavior, personal commitment, and continuous improvement;
- communicate results to management and workers.

A major problem with trailing indicators is having to wait until adverse events occur to find out if efforts to reduce such events have had any effect. Safety people have tried to teach managers how to read and understand traditional trailing indicators for safety. The trailing indicators do not always communicate safety performance in business terms that managers typically use. Most trailing indicators do not speak management language.

Chapter 3 discussed the differences between reactive approaches and proactive approaches to achieving safety. Trailing indicators usually form the basis for reactive approaches. Leading indicators offer an opportunity for proactive approaches for improving safety performance. Very often leading indicators fit within the language of business management.

Various leading indicators can have differing results. For example, one very successful leading indicator for a large construction company was requiring all individuals in management positions to participate in a program that developed a deeper understanding of safety and health for the company. The program required completion of 40 hours of safety leadership training and passing an examination on the subject materials covered during training. There were several incentives involved. Those successfully completing the program received a designation they could use with their name. Each person received a watch with the company logo on the face and the program completion date and the person's name engraved on the back. Some managers eligible for company vehicles were not eligible until they had completed the program successfully. The leading indicator reported how many managers in each company organization unit were eligible to participate and had completed the program. The program changed the safety and health focus of the entire company and elevated the importance of a safety culture. The program also provided a competitive advantage when bidding on construction projects. In addition, many participants asked for additional training on safety topics important for their work groups.

Another construction company introduced a similar program. Not only did it require participation by all managers within the company, it required participation by managers of all subcontractor companies. Not only was the overall result improved safety performance, but also the recovery of millions of dollars from large project insurance policies. The program significantly reduced insurance claims for projects that insurance companies rebated to the primary contractor. The company could use the funds to reward managers, employees, subcontractors, and stockholders.

35-5 SAFETY AND COST

Like any aspect of achieving an organization's goals, safety can convert to a common metric, cost. Accidents and injuries cost money. Claims cost money. So do legal fees, lost production time, and not complying with government requirements. Chapter 3 discussed direct, indirect, insured, and uninsured costs. Table 3-1 listed hidden costs of accidents. Table 35-1 lists uninsured costs. Safety and productivity go hand in hand. The costs of preventing accidents needs to contribute to the profit line of a business. The cost to

TABLE 35-1 Uninsured Costs

Deductible part of insurance policy
Lost wages for those not insured
Wages paid to injured persons not covered by workers' compensation
Overtime work required as a result of an accident
Supervisor time related to an accident
Repairing, replacing or cleaning up after an accident
Learning period for a new or replacement worker
Accident investigation cost
Costs to prepare and file reports
Uninsured medical costs
Costs of litigation activities
Other

prevent accidents should avoid expenses that would occur with accidents.

Expressing Costs

The accident costs in the United States total approximately $500 billion per year. This figure is overwhelming to most people. It has little meaning for an ordinary person. It certainly has little motivational potential. Costs need expressions that are useful. Expressing costs in the right terms can help people understand the importance of safety and its contribution to company profit. Each level in an organization may have a preferred way of expressing costs and the cost of safety. Reporting safety cost can help first-line supervisors and workers understand the importance of safety. If workers understand cost expressions, it is very likely that managers also will understand them.

One way to express cost is in dollars per $100 of pay. It is easy to understand that worker compensation premiums cost $12.85 for each $100 of salary. An employer pays $12.85 for every $100 issued on a pay voucher. It is similarly understandable that lost time costs a given department $8.50 for every $100 paid in salary.

Another way to express cost is in terms of the number of items produced. A company may bake bread or manufacture television sets. It is easy to understand that each $100 loss requires the company to produce and sell an additional 500 loaves of bread or 25 television sets. This kind of expression derived from the equation

$$\text{Cost of loss} = P(N)U \tag{35-1}$$

where

P is the profit margin in percent
N is the number of its products necessary to cover the loss
U is the unit selling price for the products

The volume of business necessary to cover a loss or expense is another way to express cost. For each $100 loss, a construction company that has a profit margin of 5% will have to bid and win $2,000 in jobs. This is shown mathematically as

$$\text{Cost of loss} = P(V) \tag{35-2}$$

where

P is the profit margin in percent
V is the dollar volume of business

If a company bids on 10 jobs for each one it gets, it must bid on $20,000 in jobs to cover the $100 loss. For a claim involving $10,000, the company must bid on $2 million and win $200,000 in jobs.

Another way to express cost is in the number of worker hours needed to cover the cost of a loss. The cost of a $100 loss for a worker who earns $20.00 per hour is 5 hr, or more than one half a day of work. The cost of a $2,000 loss requires 100 hrs of work, or more than two weeks.

Another way to present cost, particularly to managers, is to compare actual versus budgeted expenses. A company may use the history of losses or safety costs in the entire company to estimate future costs per unit of time. The time unit may be a month, a quarter, or a year. A graphical plot can compare actual costs for each period to budgeted costs. The plot will demonstrate to managers how well they are doing in controlling safety costs. Costs greater or less than the budgeted amounts become very visible. Presenting similar accident costs for individual departments makes the information more meaningful to department managers.

Another way to express cost to top managers and company shareholders is the cost of accidents/illnesses per share. An alternative is to express the cost of avoidable accidents and illness as additional earnings per share that shareholders did *not* receive.

Other expressions for cost are cost-benefit ratios, return on investment (ROI), and risk. Discussions below evaluate the first two further in the following text. Chapter 34 previously discussed risk and risk analysis.

Cost and Benefit

A popular way to justify business expenditures is comparing expenditures to the benefits achieved using financial terms. In cost-benefit analysis, the first task is to estimate the dollar values of all benefits and costs for a program. The program may be safety. Then one can compare the costs to the benefits. It is difficult to convert all costs and benefits to quantitative or financial terms. One may have to create some methods for converting qualitative items to costs. If benefits exceed costs, a program has financial value. If costs exceed benefits, the program is questionable.

There are several criteria for evaluating costs and benefits:

- the cost-benefit ratio;
- net benefits, i.e., benefits minus costs;
- rate of return, such as the annual benefit relative to cost;
- payback period, the time required to recover costs from benefits.

The parties that bear the costs are not always the ones who gain the benefits. That creates some dilemmas for decision-makers. Consider the four cases suggested in Table 35-2. The cases illustrate companies and buyers or the public. The cases present different situations regarding who pays costs and who gains benefits.

Governments use cost-benefit analysis for public policy. The main question is whether the cost to implement government regulations is worth the benefits derived. The use of cost-benefit analysis for justification of government

TABLE 35-2 Costs and Benefits for Different Parties

Case	Buyer or Public Company	Opinion
1	Benefits < costs Benefits < costs	Very unacceptable for both parties
2	Benefits > costs Benefits > costs	Very acceptable for both parties
3	Benefits < costs Benefits > costs	Unacceptable unless there is government subsidy for the company
4	Benefits > costs Benefits < costs	Unacceptable unless: (a)the condition is allowed by government or(b) compensation is made to the public

regulations was challenged in the courts. In June 1981, the Supreme Court upheld the OSHA cotton dust standards and noted the OSHAct of 1970 does not require cost-benefit analysis in setting standards. The court did rule that the law requires feasibility analysis. Feasibility means the capability of being done. Currently, in proposing new or revised regulations, OSHA and other agencies may prepare a cost analysis and estimate benefits, including human lives saved.

Another dilemma in evaluating the cost and benefits of safety is assessing an economic value for human life. A related factor is the economic value when human pleasures of activities become interrupted by disability. Is a corporate executive worth more than a laborer? Is an engineer worth more than a housewife? The answers are not easy. Placing a value on human life is not easy. However, these decisions occur regularly in resolving civil lawsuits.

Return on Investment

Return on investment (ROI) is a widely used method for analyzing the performance of investments in a company or investments for an individual. Whether investments are in stocks, bonds, or real estate, an investor wants to know the annual return from the investment. The concept suggests that a person must spend money (invest) in order to earn money on the investment (return). The concept is very similar to cost-benefit ratio.

There are costs to control hazards. A company wants to see a return on its investment. The return may reduce loss rates and reduce insurance premiums, increase productivity, or make services better.

Another aspect of ROI analysis is the time required to recoup an investment. Suppose the benefits occur in only two weeks. Someone is likely to decide to make the investment. However, should it take 5 years to gain the return, making the investment may give way to other investments with a quicker return. Many organizations have guidelines for ROI, such as six months or one year. The guidelines help with consistent decisions on investments supported by various units of the organization.

When considering how long an investment in safety takes to achieve a return on that investment, one must consider the decreasing value of money due to inflation. For example, a safety manager expects it will take two years to achieve a return on a $1,000 investment today. The rate of return is estimated at $500 per year. However, because the value of today's money will decrease, the estimate should include that. That is the concept of *present value*. One can compute present value, *PV*, from

$$PV = X/\Sigma(1+d)^n \tag{35-3}$$

where

X is a dollar amount in a future year
d is the discount rate
n is the year in the program

Example 35-1 A company plans to invest $1,000 in process changes to gain reduced injury costs of $500 for each of the following two years. What is the present value of the expected savings for the two-year period? Assume an inflation rate of 2%.

For the first year, the value of the $500 return is actually less than that based on present value.

$$\mathrm{PV}_1 = \$500/(1+0.02)^1 = \$485$$

For the second year, the value of the $500 return is even less.

$$\mathrm{PV}_2 = \$500/(1+0.02)^2 = \$481$$

During the two years, the actual total return on the $1000 investment is ($485 + $481) = $966.

Budgets

Organizations must balance income with expenses. They develop budgets that estimate income and expenses for a period, usually a year. Most functions within an organization must forecast how much money their program elements will cost. Upper management uses the estimates to project expenses. If expected income does not cover the expected expenses, there will be adjustments in the budget and individual functions may not get the funds requested. That will require a change in program plans.

Like any other organizational unit, a safety department must manage activities through budgeted funds. When operating safety programs, there are many activities that require planning and cost estimates. For example, a program may plan to train 300 employees to comply with OSHA training requirements. Someone must compute what the training activity will cost. Similarly, the safety program may need to plan for workers' compensation premiums, injury and illness treatments, process changes to improve safety performance and other items. Some of the items may expect to

reduce costs in future years, but money must cover the cost of programs for the current budget year.

Cost Accounting

The need to use safety costs in management requires keeping track of safety costs. An accounting system must track actual expenditures. There are many kinds of safety costs as noted in Table 3-1 and Table 35-1. Injuries and illness incur costs. Changes incur costs. Training, inspections, accident investigations, and other safety prevention activities incur costs. As one completes each case or program, there should be a way to track the expenses incurred.

Other Applications for Safety Costs and Benefits

Organizations can use cost information in other ways to help achieve safety. For example, accident claim rates provide a source of costs for some products. So do returns and failures of products. The data may help when selecting suppliers of parts, assemblies and components. Accident records, insurance rates, and claim records can help when selecting contractors. Cost of product failures, complaints, accidents, compliance with standards and other claims can help when setting performance incentives for suppliers and contractors.

The Business Case for Safety and Health

Like any other business initiative or change, someone must convince top management to support the initiative or change. The proposals must make good business sense, increase the profits of an organization, or provide other benefits.

Similarly, those involved in safety and health for a company must convince top management that their efforts benefit the company. This is making a business case for safety and health. There are several studies and references that offer ideas for developing a business case.[11] A National Safety Council publication[12] offers some guidelines for preparing and promoting a business case. The publication offers the following simplified procedure:

- *Choose the appropriate tone.* One can emphasize positive business aspects, negative elements, or both. Positive aspects include productivity, morale, product quality, employee retention, and similar items. Negative elements include fatalities, OSHA injury and illness rates, production downtime, etc.
- *Be aware of management hot buttons and top priorities.* Examples are cost savings, industry benchmarks, company reputation, product quality, productivity, and community relations.
- *Organize your business case.* Focus on reasoning of decision-makers. Their thinking includes return on investment for productivity, cost savings, improving organizational metrics, reducing financial risk, improving compliance, and aligning with corporate values.
- *Time your presentation.* A presentation should fit the company business planning cycle, not be given after leaders have set the company's annual budget. A presentation should allow lead time for budget development.
- *Network within your company.* Seek support for your business case from other leaders. Work with department managers. Check with accounting, human resources, and other staff departments to gain their input. Work with union leaders. Look for someone who is a good presenter to present your case.

35-6 SAFETY MANAGEMENT SYSTEMS

Many companies, industry groups, and standards have adopted use of safety management systems (SMS). A safety management system is a process or method. The SMS provides a comprehensive and orderly way for an entire organization to integrate safety and health practices into the management of the organization. Not only are safety management systems systematic, they are proactive, not reactive, and fully documented.

The models for safety management systems differ somewhat. One model is that of the International Civil Aviation Organization (ICAO). For some time it has required safety management systems in the management of aviation systems by member companies. Its model incorporates three principles:

- Develop a comprehensive description of the system and its components. The assumption is that most hazards come from interactions among multiple system components. The components include system functions, human performance, hardware, software, procedures, operational environment, contracted and purchased products and services, and interactions with other systems.
- Conduct an analysis of elements needed for SMS using gap analysis to identify other elements needed. The end product is an SMS implementation plan.
- Identify differences from other management systems. The focus of SMS is on safety performance. In contrast, quality management systems focus on products and services. However, SMS may incorporate parts of a quality management system.

ICAO publishes several documents[13] to help aviation organizations implement a safety management system.

Figure 35-3 illustrates the model for SMS used by the International Labour Office (ILO). ILO publishes a guideline[14] and other resources on safety and health management systems. Its model involves five elements, all working within a focus on continual improvement.

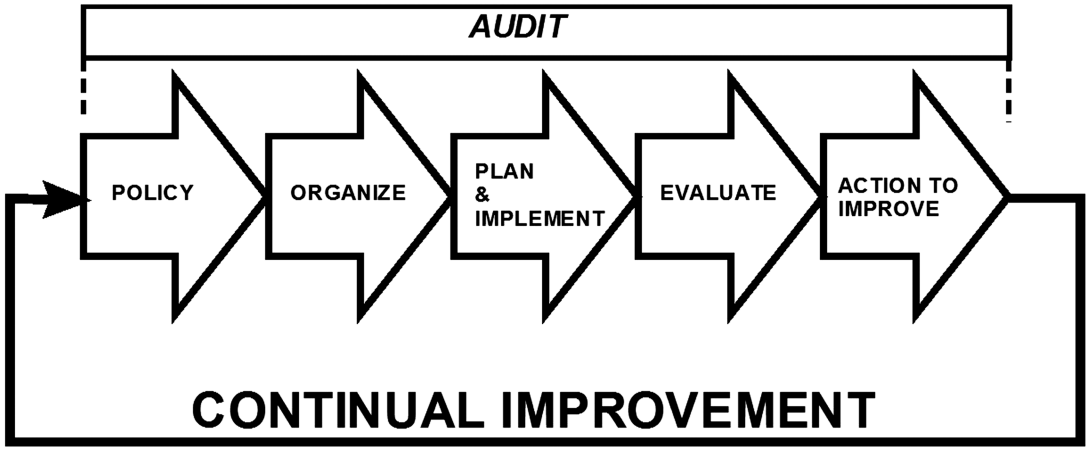


Figure 35-3. Schematic diagram of a safety management system.

1. *Policy*: An organization should have safety and health policy that includes participation by workers and their representatives. The policy should assure worker participation in all aspects of safety and health to include emergencies and safety and health committees.
2. *Organizing*: The employer and its management should allocate responsibility, accountability, and authority for implementation of policies, applicable procedures, and safety and health objectives and plans. The employer should ensure competence and training for all who participate in SMS. The SMS must include organized and effective documentation and effective communication both downward and upward in the organization.
3. *Planning and implementation*: This element includes evaluation of existing safety and health management elements, applicable laws and regulations, identification of risks, and implementation of controls. It includes planning, developing, and implementing the components of the SMS. It establishes safety and health objectives and hazard prevention. It addresses management of change, emergency management, procurement and contracting
4. *Evaluation*; This element covers monitoring, measuring and recording safety and health performance, including selection of performance indicators. It includes investigations of events, audits of operations and management reviews.
5. *Action for improvement*: Included here are identifying non-conformities and their root causes, creating improvements to the SMS itself and related safety and health details. This element manages continual improvement planning and implementation.

Other standards[15] offer similar models for safety management systems.

Audits

One approach for identifying opportunities to improve a safety program is use of audits. An audit is a process of having one or more individuals evaluate a department or a business unit. The individuals are not from the visited department or unit. An audit can vary in depth.

To a great extent, use of audits stems from quality management practices that began with ISO 9000 and related standards. The concept requires companies seeking to achieve ISO 9000 certification to thoroughly document their management systems to ensure quality defined by the standard. Then independent auditors visit the company and its operations to verify that it conforms to the standard and to internal policies and procedures. Later, international standards applied the overall process to other areas, including safety and health.

The purpose of an audit is to ensure compliance with standards and to challenge existing policies, procedures, and practices and their underlying concepts and principles. An audit can look at leadership, compliance with policy, rules and standards, and the effectiveness of safety and health procedures. It may uncover opportunities to improve in the future. Auditors must handle their visit cautiously. They are not trying to place blame or ridicule people in the department or business unit.

Within a company, a safety specialist or team of management and safety specialists may conduct an audit of a department. Table 35-3 is a list of audit questions directed primarily at chemical processes. However, the questions are typical of many audits. When finished, an audit team presents its findings to the leaders of the organizational unit visited. The report covers items needing improvement and ways to achieve them. The findings should also address policy and procedural problems that need adjustment to make safety and health more effective.

One auditing organization provided a list of top SMS areas to improve based on their audits of several

TABLE 35-3 Questions Typical of a Safety Audit[a]

1. Are written instructions for the operation in place?
2. Are the instructions current? Has the process changed? Do engineering drawings reflect unit modification? Have modifications been reviewed for process safety?
3. Do the operators follow the written instructions?
4. Is the equipment correct for the process?
5. Are reactants handled and stored correctly?
6. Are necessary items of personal protective equipment in the correct locations?
7. Is ventilation sufficient?
8. Is electrical equipment compatible with the area processes (e.g., explosion-proof electrical equipment in an area where flammable vapors or explosive dusts are present)?
9. What hazardous materials are used in the process? How are the materials stored and in what quantity? What emergency procedures and equipment are available to handle accidental events associated with the materials' storage and usage? How are personnel trained to utilize these procedures and equipment?
10. What errors in operation are possible and within reason? What would be the consequences of such errors? Will the equipment handle these consequences with minimum risk to life and property? Are equipment safeguards in place and operable?
11. Is explosion relief venting adequate? Is the explosion relief properly directed?
12. What are the provisions for uncontrolled reactions?
13. What personal safeguards are advisable (safety showers, fire-resistant clothing, emergency care, protective equipment)?
14. What are the training provisions for new process operators? Is periodic training given to existing operators and what does it consist of? Are operators challenged by means of emergency training exercises? Is a process simulator advisable for training?
15. In addition to the sprinkler system adequacy, is additional fire protection, such as an automatic dry chemical extinguishing system or a other system, warranted? Is an explosion suppression system warranted?
16. What is the manner of receiving, storing, handling and transferring hazardous materials and combustible liquids and gases? What controls exist to eliminate contamination of product that could create hazardous polymerization as well as accidental release? What are the most likely possibilities of accidental release? What safeguards exist?
17. Are contamination sensitive bulk materials stored above or below ground? If below grade, what steps are taken to prevent contamination and degree of assurance?
18. Are critical spare parts on hand/such as parts for circulation pumps for refrigeration systems on temperature sensitive materials stored in bulk?
19. Is an emergency dump system needed? If already in place, is it adequate?
20. Are critical maintenance procedures identified? Are personnel trained?

[a]Derived from S. P. Krivan, "Avoiding Catastrophic Loss: Technical Safety Audit and Process Safety; Review," *Professional Safety*, February: 21–26 (1986).

aviation-related companies.[16] The most common recommendations and associated portions of audits conducted fell into the following areas:

- Internal evaluation program (71%)
- Safety management system training (61%)
- Safety management system manual (52%)
- Hazard reporting (45%)
- Improved risk assessment (43%)
- Safety committee (40%)
- General operating manual (32%)
- Safety policy (31%)

A report across organizations helps individual organizations assess performance with other organizations in its industry. The report results allow a form of benchmarking.

Safety Culture

People describe an organization with high performance including safety and health performance as having a strong culture. Many groups seek to achieve an effective safety culture. Culture is not something you can see or measure directly. An effective organizational culture occurs when all members of the organization perform in a similar manner that reflects the values and practices pursued by the organization. A strong culture is getting a group of people to perform consistently and properly. In safety, it means following written procedures, collaborating on safety practices, assisting each other to do tasks correctly, consistently, and safely.

Some attributes of a strong safety culture include the following:[17]

- Demonstrated management commitment to safety.
- Integrating safety as a value of the organization.
- Assuring accountability at all levels.
- Improved supervisory leadership.
- Empowering and involving workers in safety planning and decision-making.
- Clear and consistent communication about safety and its impact on productivity.

- Training all employees regarding their role in the organization's safety performance.
- Getting top management to promote safety as a value.

EXERCISES

1. A fast food hamburger restaurant operates on a 4% profit margin.
   (a) If hamburgers sell for $1.75 each, how many hamburgers must the restaurant sell to cover lost profits from a $1500 accident?
   (b) If the restaurant sold only hamburgers and on average sold 1,000 each day, how many days of profit does it lose because of the accident?
2. A car company decides to reduce cost by not installing an $75 per car safety improvement. If a human life is assumed to be worth $875,000 on the average, how many automobiles would have to be produced to cover 13 death claims per year?
3. A safety manager recommends spending $3,000 on an initiative to reduce accidents in an organization. Assume the company has a 3% profit margin. The manager believes the investment will take three years to recoup the expenses. What is the present value of the investment over the three-year period?
4. Obtain a chart of an organization. Identify where safety elements of the organization are located. Suggest where improvements might be made and what the changes would accomplish.
5. Find a company that has implemented a safety management system. Identify the process it follows. Explore how it implements each element of its process.
6. Find a company that has developed a business case for its safety and health programs. Determine what cases it used to show the value of the programs to the company's management team.

REVIEW QUESTIONS

1. Describe what managers do.
2. How is safety implemented in an organizational structure?
3. Explain the role of safety specialists in an organization.
4. How can management style affect safety in an operation?
5. Why is accountability important in managing safety?
6. How is paying attention to details related to successful safety programs?
7. How is enforcement useful in safety management?
8. Identify ways to express costs of safety to
   (a) workers
   (b) managers
9. Explain how cost and benefit can be used to justify safety programs.
10. Explain return on investment and how it can be used for safety.
11. How can safety cost be used to select and provide incentives for contractors and suppliers?
12. What are five leading indicators that a company can use to measure its safety and health performance?
13. What is a safety management system? How is it different from running a safety program?
14. What is a safety audit? What is its purpose?

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CHAPTER 36

SYSTEM SAFETY

36-1 INTRODUCTION

System safety is an approach to accident prevention that involves the detection of deficiencies in system components that have a potential for failure or an accident. Some component deficiencies lead to failures for the entire system. System safety is the application of technical and managerial skills to the systematic, forward-looking identification and control of hazards throughout the life cycle of a system project, program or activity. People developed system safety methods especially for complex systems.

In this definition, a system is an item of equipment, a facility, or a process. Examples of complex systems are aircraft, weapons, missiles, satellites and space equipment, production plants, vehicles, computers, software, instrumentation, power grids, and buildings.

Chapter 3 discussed preventive strategies for accidents. A preventive strategy (Figure 3-4) does not allow accidents to happen before something is done about them. This is in contrast with a reactive strategy (Figure 3-3) that acts after accidents have occurred. The latter is costly and often ineffective. Existing designs and systems often limit the possible changes sought by a reactive approach. As noted in Figure 30-1, the later in a design and development process someone makes changes, the greater the cost for a change. Because of cost or a pre-existing feature of a system, a change may not be as comprehensive as desired. There are constraints that limit the effectiveness of a change.

The concepts for system safety began with aircraft and missile projects in the 1950s and 1960s. Often there were only one or a very few models developed and tested. They were prototypes. There was no room for major failures because there was no money to build another model. In some cases, a prototype never reached production. Even production models could not afford many failures. They were very expensive. They drew a lot of public attention. Therefore, organizations needed methods to eliminate or reduce hazards and failures from the beginning of the design and development phases.

System safety methods focus on hazard analysis for components of a system or the entire system. A goal is to eliminate hazards or reduce them to acceptable levels. The methods address the entire life cycle of a system, from concept to prototype, production, and operation. The hazard analysis may apply to any of the system phases and the individuals and organizations responsible for them. The intent is to recommend and apply suitable controls for the hazards to designers, production units and system users and operators. The system safety team applies safety and health knowledge discussed throughout this book. Members of the team usually have extensive knowledge about safety and health hazards, controls, and associated laws, regulations, and standards.

System safety methods also focus on failures of components and complete systems. Of particular interest are those that lead to injury, illness and loss of property, or of the systems. Methods often include risk assessment and analysis.

Many of the approaches developed in system safety have carried over into other areas of safety practice. For example, Chapter 24 introduced process safety, methods used in achieving safety in chemical and petroleum plants and facilities. Many of the techniques applied in process safety came from system safety. System safety methods find uses in other areas of safety practice as well. The methods help in product, building and facility design (see Chapter 30) and in accident prevention management.

36-2 GENERAL PROCEDURES

There are some organizations that have formal requirements for system safety practice. As noted, OSHA includes system safety methods in its performance standard for process plants.[1] OSHA also offers guidance on the use of this standard.[2]

The Department of Defense has a long-standing standard on system safety.[3] The standard covers methods and procedures. The Department of Defense also extends system safety practices to software development[4] and other procurement regulations. Software is often an integral and critical part of aircraft, weapon, and other systems. Software can introduce hazards for those involved with a system.

Safety and Health for Engineers, Third Edition. Roger L Brauer.
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CASE 36-1

February 1, 2002, Flying over Texas and Louisiana. Before dawn that morning, NASA space shuttle Columbia began its descent from orbit around the Earth following the 15-day mission of STS-107. As the shuttle approached Texas, it began to disintegrate. Before long the communications went silent and debris scattered across two states. NASA put a broad search effort into place to collect the debris.

NASA convened the Columbia Accident Investigation Board (CAIB). It looked at many aspects of this mission and its flight. It considered other organizational and cultural factors.

CAIB concluded that the immediate cause of the accident occurred at launch. A piece of foam broke from the External Tank just after launch and struck the leading edge of the shuttle's left wing at a speed of 400–570 mph. The damage occurred to the special insulation needed during reentry. The insulation protects the shuttle from the high temperatures that occur during reentry. With a missing or damaged piece of insulation, the wing heated and began to come apart. Within a couple of minutes that led to the loss of the entire vehicle and crew of seven.

One of the additional conclusions of CAIB was the failure of NASA to integrate its safety program effectively into management decisions. The conclusion was similar to the findings of the Rogers Commission Report for the loss of the shuttle Challenger a few years earlier (Case 35-1).[a]

[a]www.nasa.gov/columbia/home/CAIB_Vol1.html

The National Aeronautics and Space Administration, a leader in the development and application of system safety methods and practices, has publications on system safety.[5]

The Nuclear Regulatory Commission uses some system safety methods in design and operation of nuclear power plants.[6] The National Institute of Occupational Safety and Health published information about the use of system safety methods in occupational safety and health.[7]

OSHA Process Safety Standard

The OSHA Process Safety Standard incorporates many system safety concepts. Also see Chapter 24. For example, the standard calls for an experienced team to identify and analyze hazards (process hazard analysis or PHA) using one or more of the following methods:

- What-If/Checklist
- Hazard and Operability Study (HAZOP)
- Failure Mode and Effects Analysis (FMEA)
- Fault Tree Analysis
- An appropriate equivalent method.

The analysis then addresses:

- hazards of the process;
- identification of previous incidents that had a potential for catastrophic consequences in the workplace;
- engineering and administrative controls;
- consequences of failure of engineering and administrative controls;
- facility siting;
- human factors;
- qualitative evaluation of possible safety and health effect of control failures.

The final step is establishing a management system to address the team's findings and recommendations in a timely manner through an action plan and schedule.

Military Standard 882

Different organizations have variations for the application of system safety methods and procedures. Military Standard 882 (MIL-STD 882) addresses an approach for mishaps and risks encountered during the development, testing, production, use, and disposal of systems, subsystems, equipment, and facilities. Those engaged in military acquisitions have used the procedures in MIL-STD 882 for a long time to identify, evaluate, and mitigate mishap risks to an acceptable level.

The standard includes definitions of terms. A few key terms are:

- *Mishap:* an event or series of events resulting in unintentional death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.
- *Risk:* the probability of occurrence and the severity of a mishap. There are six probability levels: Frequent, Probable, Occasional, Remote, Improbable, and Eliminated. There are four severity levels: Catastrophic, Critical, Marginal, and Negligible. The levels form a risk assessment matrix, shown in Figure 36-1.

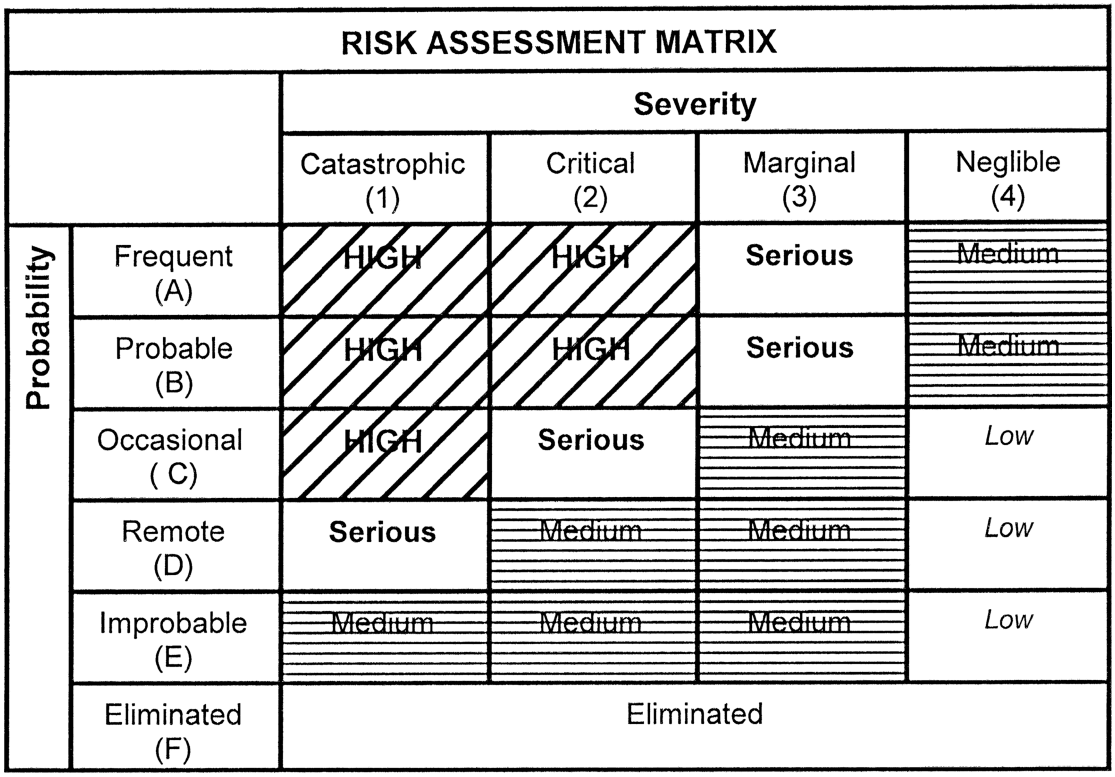


Figure 36-1. Example of a risk assessment matrix that is part of a system safety method.

The matrix includes letter codes (probability) and number codes (severity). For descriptions of codes, see Tables 36-1 and 36-2.

- *Safety:* the freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.
- *System:* an integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective.
- *System safety:* the application of engineering and management principles, criteria, and techniques to achieve acceptable mishap risk, within the constraints of operational effectiveness and suitability, time, and cost, throughout all phases of the system life cycle.

The standard outlines the eight elements of the system safety process. The elements are:

1. Document the system safety approach.
2. Identify and document hazards.
3. Assess and document risk.
4. Identify and document risk mitigation measures.
5. Reduce risk to an acceptable level.
6. Verify, validate and document risk reduction.

TABLE 36-1 Suggested Mishap Severity Categories

Description	Category	Environmental, Safety and Health Result Criteria
Catastrophic	1	Could result in death, permanent total disability, loss exceeding $1M, or irreversible severe environmental damage that violates laws or regulations.
Critical	2	Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, loss exceeding $200K but less than $1M, or reversible environmental damage causing a violation of law or regulation.
Marginal	3	Could result in injury or occupational illness resulting in one or more lost work day(s), loss exceeding $10K but less than $200K, or mitigatible environmental damage without violation of law or regulation where restoration activities can be accomplished.
Negligible	4	Could result in injury or illness not resulting in a lost work day, loss exceeding $2K but less than $10K, or minimal environmental damage not violating law or regulation.

TABLE 36-2 Suggested Mishap Probability Levels[1]

Description[2]	Level	Specific Individual Item	Fleet or Inventory[3]
Frequent	A	Likely to occur often in the life of an item, with a probability of occurrence greater than 10^{-1} in that life.	Continuously experienced.
Probable	B	Will occur several times in the life of an item, with a probability of occurrence less than 10^{-1} but greater than 10^{-2} in that life.	Will occur frequently.
Occasional	C	Likely to occur some time in the life of an item, with a probability of occurrence less than 10^{-2} but greater than 10^{-3} in that life.	Will occur several times.
Remote	D	Unlikely but possible to occur in the life of an item, with a probability of occurrence less than 10-3 but greater than 10-6 in that life.	Unlikely, but can reasonably be expected to occur.
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced, with a probability of occurrence less than 10^{-6} in that life.	Unlikely to occur, but possible.

[1]The probability that a mishap will occur during the planned life expectancy of a system, quantified in terms of potential occurrences per unit of time, events, population, items, or activity.
[2]Definitions of descriptive words may be modified based on quantity of items involves.
[3]The expected size of the fleet or inventory should be defined prior to accomplishing an assessment of the system.

7. Accept risk and document.
8. Manage life cycle risk.

The standard includes procedures for dealing with software that contributes to risks in a system. There are tables for assessing software criticality. The standard also lists tasks used selectively in specific system safety projects. Each task identifies its purpose, description, and details.

NASA System Safety

NASA was an early user and developer of system safety methods for its complex systems. Most people recognize that space exploration is a risky business. The agency has introduced some concepts that are worth noting. One is *risk-informed safety case*, intended to determine if something is adequately safe. Another concept addresses the problem of what is adequately safe. NASA uses the term *as safe as reasonably practicable*. The *NASA System Safety Handbook* explains the concepts further (note 5).

Risk-Informed Safety Case (RISC) NASA describes RISC as:

> A structured argument, supported by a body of evidence, that provides a competing, comprehensive and valid case that a system is or will be adequately safe for a given application in a given environment. The process accomplishes this by addressing each of the operational safety objectives negotiated for the system. It includes articulation of a roadmap for the achievement of safety objectives that are applicable to later phases of the system life cycle. RISC emphasizes that a determination of adequate safety is the result of a deliberative decision making process that necessarily entails an assessment of risks and tries to achieve a balance between the system's safety performance and its performance in other areas.

As Safe As Reasonably Practicable (ASARP) NASA describes ASARP as follows:

> A determination that a system is ASARP entails weighing its safety performance against the sacrifice needed to further improve it. The system is ASARP if an incremental improvement in safety would require a disproportionate deterioration of system performance in other areas.

36-3 PRELIMINARY HAZARD ANALYSIS (PHA)

Preliminary hazard analysis is one of the early steps in a system safety project. This step also creates assessments of risks associated with each hazard. This step defines possible corrections for the risks. The product of this step is a tabular inventory of hazards for the system under consideration. The PHA fits best during early system stages, such as concept definition, design, and development.

The procedure covers numerous details for each hazard. The following are typical data elements:

1. Valued resources protected, such as personnel, facilities, equipment, productivity, mission objective, and environment.
2. Identify the levels of acceptable risk approved for the project that appear in the risk assessment matrix.
3. Identify system element affected and related assumptions.
4. Identify the hazards through brainstorming and other techniques and the system targets the hazards threaten. One may organize the list of hazards various ways for convenience. Examples are sorting hazards by subsystem or system target.
5. Assess hazards for severity and probability based on worst-credible (not worst-possible) cases.

PRELIMINARY HAZARD ANALYSIS WORKSHEET								
System	Subsystem			Phase		ID		
Date	Period Covered			Analyst				
	Current Risk					Resulting Risk		
Hazard & Description	Sev	Prob	Cost	**Proposed Action and Target Code[1]**		Sev	Prob	Cost

[1] E - Equipment, P - Personnel, F - Facility, R - Product, O - Operations, N - Environment

Figure 36-2. Example of a chart for use in conducting a preliminary hazard analysis.

6. Assess risk for each hazard applying the approved risk assessment matrix.
7. Rate each risk as acceptable or unacceptable or develop controls for the risk.
8. Identify the hazard control priority category that applies (see also Chapter 9).
   1. Eliminate the hazard.
   2. Reduce the hazard level.
   3. Provide safety devices.
   4. Provide warnings.
   5. Provide safety procedures (and personal protective equipment).
9. Re-evaluate the risk with the controls in place to identify any reduction in classifications in the risk assessment matrix.
10. Evaluate risk with controls in place to determine if the controls introduce any new hazards for the system.

Figure 36-2 provides an example of a preliminary hazard analysis chart. Referring to the chart, one can see that PHA can capture a lot of details for each hazard.

36-4 FAULT TREE ANALYSIS

Fault tree analysis is another commonly used system safety method. H. A. Watson at Bell Telephone Laboratories originated fault tree analysis in 1962.[8] It is most suitable for complex systems. It is a Boolean logic concept that evaluates *events*.

The procedure relies on building a tree structure as shown in Figure 36-3. At the top is the principal or top undesired event. The tree continues by breaking the event into contributing factors and further subdividing them into event causes. Fault tree analysis is a deductive process that moves from the general to the specific. A tree chart considers the causal chain of factors leading to the top event. Interactions between events and elements of the system are a vital part of this method.

Fault tree analysis as applied to system safety relies on preliminary hazard analyses (PHA) or other analysis techniques to identify major undesirable events. After constructing a tree, a system safety team applies qualitative or quantitative analyses to elements. To perform quantitative analysis on a tree, team members must apply a probability to each event cause. Today, computer systems make the

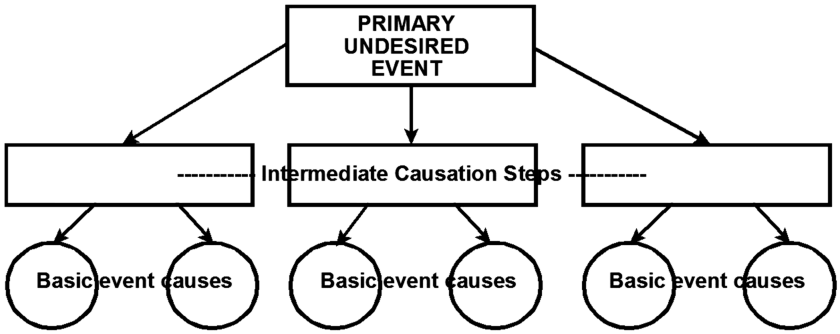


Figure 36-3. Fault tree concept. (Reprinted with permission from H. E. Roland and B. Moriarty, *System Safety Engineering and Management*, John Wiley & Sons, New York, 1983.)

procedures of constructing and analyzing fault trees quite easy. Qualitative analysis can provide insights into fault paths and critical event causes.

Limitations of Fault Tree Analysis

Analysis of a fault tree can be no better than the events identified for it. A major limitation of fault tree analysis is failure to identify all the events that may lead to a top event. Failure to include an event may simply be oversight. However, it may also be a lack of experience and knowledge of the system and its behavior or potential behavior. Early in the design and development of a system it is difficult to anticipate failures and undesired events. Team members may not have insight into the possible failures in the future. Team members may have limited knowledge and experience with materials and components that make up a system.

Another significant difficulty is assigning valid probabilities to event causes. There are considerable data on equipment performance from reliability engineering and other sources. However, placing probabilities on human activities with precision is difficult. Humans behavior under ideal conditions may be significantly different compared to stressful, boring or distracting conditions. In addition, different people act quite differently under the same conditions. Data banks on human errors provide reasonable information on simple human errors. In contrast, there is little information for estimating mistakes on higher-level tasks involving cognitive functions.

Another limitation on the use of fault tree analysis is cost. Compiling the knowledge for, constructing the fault tree, and assigning probabilities to tree elements can be laborious and costly.

Fault Tree Symbols

Fault tree analysis uses a particular set of symbols. Figure 36-4 illustrates commonly used symbols. There are some variations in symbology among practitioners.

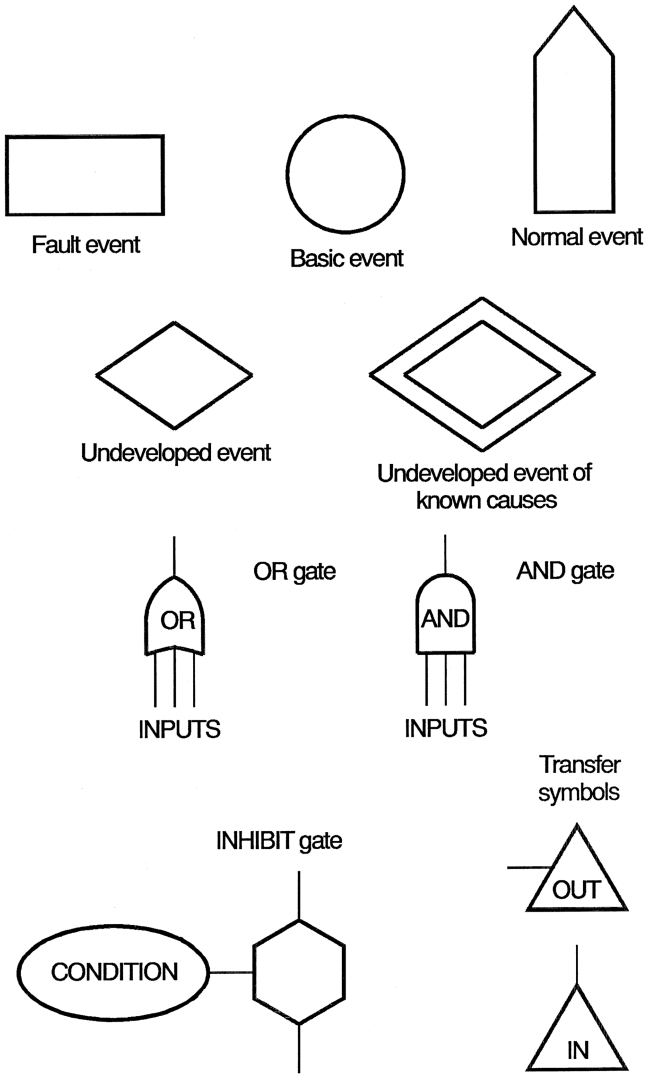


Figure 36-4. Symbols commonly used in fault tree analysis.

Events There are four kinds of events. There are symbols for each. A rectangle represents a *fault event* as a top or intermediate event that a tree must describe further. In a quantitative analysis, a probability for a fault event results from computation of elements below it in the tree.

A *basic event*, represented by a circle, is an event having no further analysis. It is a terminus of a branch in the fault tree. Basic events have probabilities when there is quantitative analysis.

A diamond represents an *undeveloped event*. It is an event that an analyst chooses not to analyze. Although it may merit further analysis, an undeveloped event may simply be a curiosity or may not be critical to the problem at hand. Analyses may result in assigning a probability to an undeveloped event. Sometimes there is an undeveloped event, but the analysis team may have deeper knowledge about that branch of the tree. Some people use a double diamond for undeveloped events.

A *normal event* is one that has two states: it occurs or does not occur. A house shape represents a normal event. Some call these *switch events* because of the two states. In many cases analysis of a tree should consider normal events in each of their two states. Frequently normal events have probabilities of 1.0 or 0.0. Sometimes there are other probabilities.

Logic Gates Elements in a fault tree become related by Boolean algebra. Symbols depict the kinds of relationships among elements. Basic logic relationships are ***OR*** and ***AND***, represented by gate symbols. Both AND and OR gate symbols have unique shapes, as shown in Figure 36-4.

An OR gate indicates that any of the input events can cause an output event. Under quantitative analysis, one computes the output probability by summing probabilities of input events attached to an OR gate. For an OR gate, the output event always has a higher probability than any of the input gates.

An AND gate indicates that all of the input events must occur to cause the output event. In quantitative analysis, one computes the output probability by calculating the product of all input events. Often probabilities for output events tied to an AND gate are less than probabilities for input events.

Special Notations There are other logical relationships that can occur in a fault tree. Various notations included with AND and OR symbols indicate the special logical relationships. Some notation systems use other symbols for special logical relationships. For example, two input events for an OR gate may be mutually exclusive. One excludes the other from occurring. An *exclusive* notation attached to the OR gate indicates this condition.

There may be a condition in which at least two of three input events are necessary for an output event of an AND gate. A notation "$A_i \geq 2$" attached to the AND gate would note this special condition.

In another situation one or more input events may need to occur before a third one has any consequence. This is a *priority modification*. A notation "$C \rightarrow R_1, R_2$" would indicate that input event C is not significant unless input events R_1 and R_2 occur first.

Another variation is a *summation gate*. This gate type has a possibility of having input events requiring certain levels before the output will occur. A summation gate may apply to either an OR or an AND gate. A summation sign or note with the gate indicates this special condition.

Sometimes a complex array of conditions determines if an output event will occur at a gate. An "M" notation on a gate indicates that such a gate processes a complex matrix of conditions.

For some events, certain conditions must be present to include the input events in the tree. The input events may inhibit or enable the output event. A hexagon symbol represents an *inhibit gate*.

A fault tree may have several pages. One page may not have enough space to diagram a complete fault tree. A *transfer symbol* in the shape of a triangle represents discontinuities between pages. Identifying numbers or letters on both segments of a drawing indicate where they tie together. A transfer symbol can also represent multiple, identical branches at multiple locations in a tree.

Events

An event describes any element of a fault tree that represents an occurrence. Events may be *normal events*, *failures* or *fault events*. Failures are attributes of components that interrupt the function of the component. For example, an electronic relay that sticks open is a failure event.

Fault events are events that contribute to component or system faults. A fault is a condition (not necessarily a failure) of a system, subsystem or component that contributes to the possible occurrence of an undesired event. For example, failing to act in response to a fire alarm is a fault, but a deaf person not being able to hear an alarm is a failure.

There are four classes of causal events that appear in fault trees. *Primary* refers to internal attributes or conditions of components. *Secondary* refers to something outside a component. Each can occur with failures or faults, which completes the four classes.

Primary Failures Primary failures are internal problems that make components inoperative. Repairing a primary failure returns a component to full operation. A primary failure is also a failure of a component within the design envelope. A primary failure may be an inherent characteristic of a component that causes the component to fail. The

primary failure of one component cannot contribute to the primary failure in another component.

Secondary Failures Secondary failures are external problems that make components inoperative. Repairing a secondary failure does not return a component to operation. A secondary failure is the failure of a component outside the design envelope, such as environmental conditions that affect a component. A primary or secondary failure of one component or a group of components can cause a secondary failure in another component.

Primary Faults Primary faults are abnormal events within an operation. They can lead to undesired conditions in a system.

Secondary Faults Secondary faults are external event causations. One form of secondary fault is a command fault, an inadvertent operation of a component due to failure of a control element. An example is accidentally bumping a control switch that energizes a circuit.

Constructing a Fault Tree

Development of a fault tree begins by selecting the top event. The top event is the most important, most severe, or most undesired event. Once there is a top event, one can begin to construct the fault tree.

The first tier of events includes those that are necessary and sufficient causes for the top event. One can add tiers together with logical relationships. It is better to include generic causes at upper levels in a fault tree. This makes it easier to include detailed faults and failures in the tree structure.

Analyzing a Fault Tree

There are several approaches to analyzing a fault tree. Methods involve quantitative and qualitative analysis.

Qualitative Analysis of Fault Trees Creating a fault tree gives analysts insight into the causes of an undesired event. It also give insight to system behavior. A qualitative analysis can make the fault tree exercise worthwhile.

Evaluating elements of a fault tree helps gain further insight into the causes of a top event. The branches help identify the likelihood of faults or failures contributing to the top event. The evaluating team can look at sequences and focus on those most likely to occur.

Another approach is to find the most likely sequences by analyzing the gates using products of input events for AND gates and sums of input events for OR gates.

Products of values (AND gates) less than one are smaller than their sums. Sums of OR gates increase above the values in lower branches. Branches linked by OR gates typically have high probabilities of occurrence, whereas branches linked by AND gates typically have low probabilities of occurrence.

Quantitative Analysis of Fault Trees Quantitative analysis begins at the bottom end of each branch. One must assign a probability to each basic and normal event. One may also assign a probability of occurrence to each undeveloped event.

Then one must apply Boolean algebra to each logic gate to determine the probability of each intermediate event. Ultimately, the analysis calculates the probability for the top event. Example 36-1 illustrates the fundamentals of this process for the fault tree shown in Figure 36-5.

Cut Sets Cut sets are any sequence of events (reading from the bottom of a branch to the top event) that leads to the occurrence of the top event. One can analyze each sequence that leads to the top event. Then one can compare all sequences leading to the top event. The comparison will identify which sequence is most likely to cause the top event.

Example 36-1 For the fault tree in Figure 36-5, the probabilities for some of the events are as follows:

Event	Probability for Events (frequency in days)
D	3.45×10^{-7}
J	6.89×10^{-4}
K	7.33×10^{-3}
L	6.05×10^{-3}
M	1.88×10^{-4}

What is the most likely cause for event B?

The probability for event D is given. The probability for event E is

$$P(\mathrm{J}) \times P(\mathrm{K}) = (6.89 \times 10^{-4})(7.33 \times 10^{-3}) = 5.05 \times 10^{-6}$$

The probability for event F is

$$P(\mathrm{L}) \times P(\mathrm{M}) = (6.05 \times 10^{-3})(1.88 \times 10^{-4}) = 1.137 \times 10^{-6}$$

Event E is the most likely cause. However, event F has a very similar probability and requires careful consideration when selecting controls.

36-5 FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

Failure mode and effects analysis (FMEA) is an inductive procedure that moves from the specific to the general.

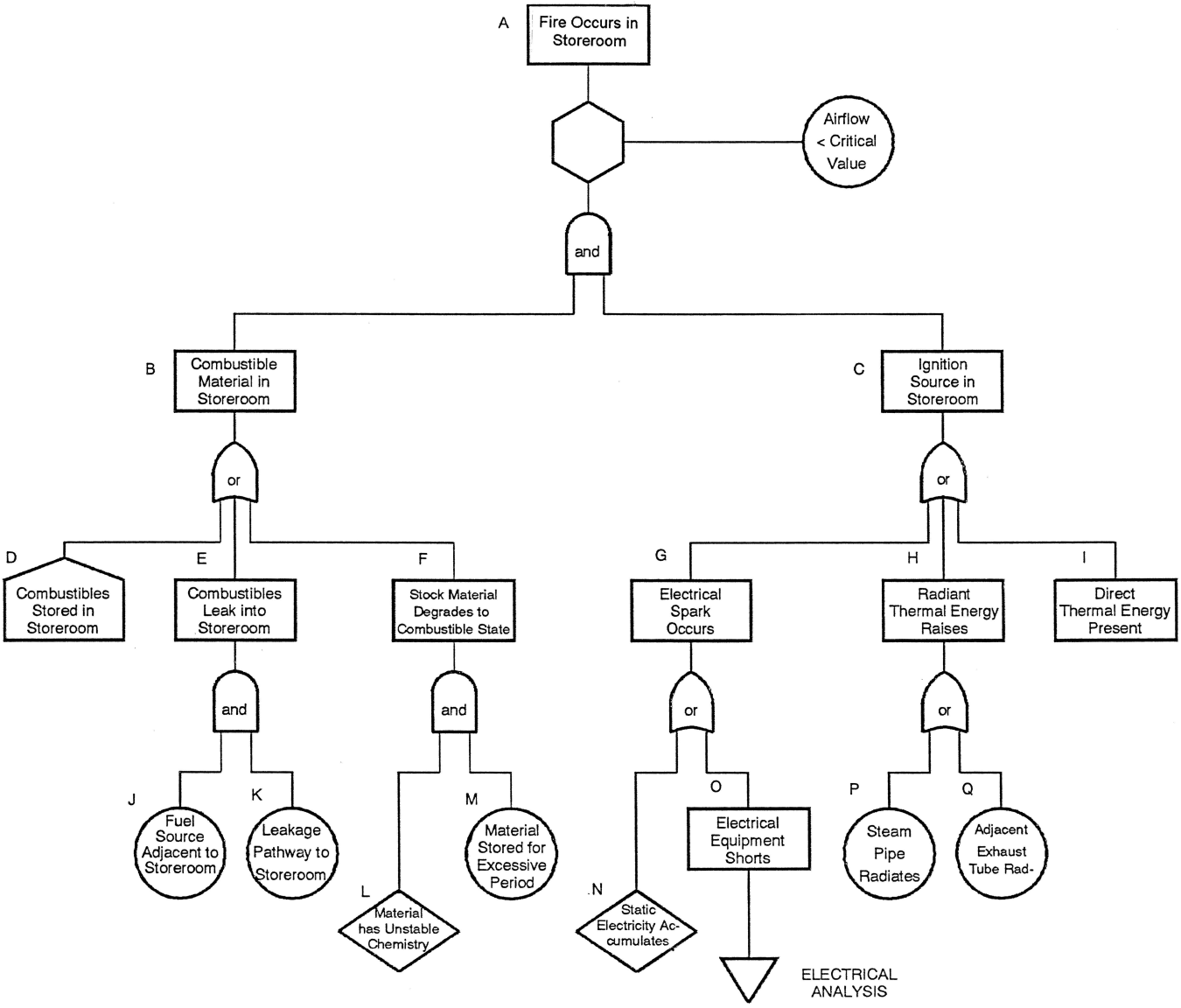


Figure 36-5. Example of a fault tree. (From *Facility System Safety Program Manual*, HNDP 385-3-1, U.S. Army Corps of Engineers, Huntsville Division, Huntsville, AL, October 1985.)

Diagnostic charts for automobile and appliance repair are essentially FMEA charts. FMEA emphasizes *conditions*, not events. FMEA analyzes *equipment* or *components*. It relates conditions of components to conditions of the system of which they are a part. The analysis traces failures in components to determine their effects on the system. Of interest in system safety are effects that impact safety.

FMEA uses special tables and charts to log data during the analysis. One element of a typical worksheet is a *component description*. The worksheet identifies the individual or combinations of components being analyzed. The worksheet has a column for *failure mode*. Additional columns list *effects on other components* and *effects on the system*. The worksheet also contains a column to identify the hazard category or risk assessment code (see Figure 36-1). It may also estimate *failure frequency* and *effects probabilities*. Those estimates may be qualitative or quantitative. Finally, there is usually a column to identify *control method*. It indicates how to prevent the failure or how to protect against its consequences.

In working across the data columns of a FMEA chart, users must recognize there are many potential relationships among data elements. For example, often there is more than one failure mode for each item, one cause for each failure, or one effect for each cause.

After completing a FMEA, the procedure involves development of a critical item list (CIL). This list contains

FAILURE MODE AND EFFECTS ANALYSIS								
System		Subsystem		Date	Analyst		Page	
Component or Part Name & Description	Failure Mode	Cause of Failure	Effect on...			Risk or Hazard Category	Probability of Effect	Comments
			Other Components	System	Personnel			

Figure 36-6. Example format for a Failure Mode and Effects Analysis (FEMA) worksheet.

failures that exceed the acceptable levels of risk. The CIL may help with more detailed safety analysis.

Figure 36-6 is an example of a FMEA worksheet.

36-6 ROOT CAUSE ANALYSIS (RCA)

When analyzing accidents, incidents, faults and other problems, the goal is to find causes to prevent such events from occurring again. Often the immediate cause is clear. However, other factors may contribute. There is a need to understand them as well.

Root cause analysis seeks to uncover underlying causes for adverse events. The method is useful also for good events. NASA developed root cause analysis. A root cause is a cause that will not lead to an event if the cause is not in place. A cause that is not a root cause is a factor that affects the outcome of an event.

There are several applications for root cause analysis. It has use in safety and failures, in quality control when studying reasons for nonconformance with quality practices, in processes, and in systems.

Root cause analysis procedures begin with a description of a problem or event. The next step is identifying one or more causes for the problem or event. A cause answers *why* the problem or event occurred. It includes understanding the effect that results from a cause. The analysis considers what was required to produce the effect.

The first and immediate cause becomes an event for further analysis. The procedure continues by asking *why* the first cause occurred, what was required to produce it and finding a cause for it. The second cause becomes another event for additional analysis. The procedure continues until one or more root causes emerge.

Causes may occur together as a combination of factors. Not all causes act alone to create an effect. Effects often have two or more causes that occur together. An AND would link the multiple causes that occur together.

The procedure continues until there is a root cause. It is possible that analysis does not uncover a root cause that meets the definition.

One way to track the analysis is to diagram the initial problem or event and associated causes. Most users of RCA prefer to use block diagrams for each event and cause, laid out horizontally. The overall diagram continues expanding horizontally with the addition of each level of cause.

Some use additional charting techniques when seeking causes. One example is the Ishikawa "fish diagram."[9] Many people use this diagram in dealing with quality. It applies a concept that includes people, methods, machines, materials, environment, measurements. That model is similar to the hazard control models introduced in Chapter 9. They included the 4M's and the Goal Accomplishment Model.

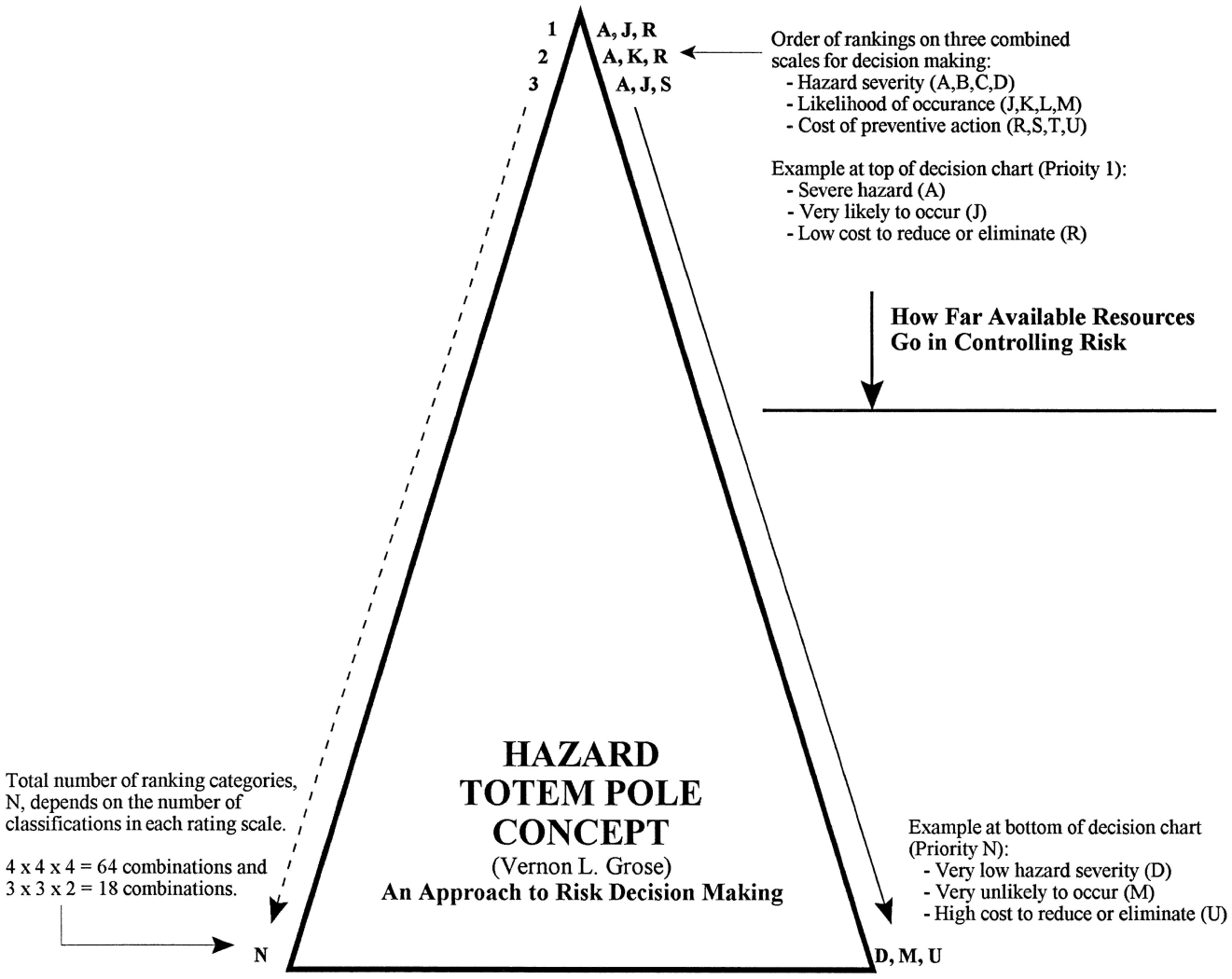


Figure 36-7. Hazard totem pole concept.

36-7 HAZARD TOTEM POLE

Grose[10] applied system safety principles and techniques in preparing hazard control information for management decisions. His process creates a simplified decision chart, the Hazard Totem Pole (Figure 36-7).

His process begins by describing "scenarios," situations that can go wrong. Each organizational unit or functional element of an operation develops the scenarios based on group experience. Each scenario is a hazard or contains a hazard. Three ratings get attached to the hazards in each scenario. The ratings are (a) severity; (b) probability of occurrence; and (c) cost to correct. Rating classifications come from tables created for each rating type. For example, tables may have four categories each. Ratings use letters for identification. Hazard severity has categories A, B, C, and D. Hazard probability has categories J, K, L, and M. Cost to correct has categories R, S, T, and U. The severity and probability tables have category descriptors similar to a risk analysis matrix (see Figure 36-1). Two of the tables have descriptions for categories very similar to those in Tables 35-2 and 35-3.

The Hazard Totem Pole uses combinations of categories from each of the three tables. With a $4 \times 4 \times 4$ classification, there are 64 combinations. A $3 \times 3 \times 3$ classification will have 27 combinations. One goal is to limit the combinations. The highest combination (A, J, R) is one with high severity consequences, a high probability of occurrence, and a low cost to implement. The lowest combination (D, M, U) has low severity, low probability of occurrence and high cost to correct. Someone must decide how to organize the categories in between the highest and lowest.

With a cost attached to each scenario, one can decide how far down the list a budget for correction will reach. If the corrective program continues to a second year, a new budget can tackle scenarios farther down the list.

The process creates a list of hazards from the analysis of scenarios organized according to the combination of ratings established in the hazard totem pole. The list forms priorities for allocating funds to correct the hazards. The list can include the cost to correct each hazard. One compares the cumulative cost as one moves down the list to funds included in a budget. Managers have limited resources and are not likely to have funds to correct every hazard in the list. They must decide how far down the list a budget reaches. At some point there is a cutoff. Funds will not support items below the cutoff line.

The funded items form an action plan to correct hazards. Periodically, there is a need to repeat the process and identify new scenarios and hazards. New funding applies to the updated hazard list with new decisions for management action.

36-8 MANAGEMENT OVERSIGHT AND RISK TREE (MORT)

Another method closely related to system safety methods is Management Oversight and Risk Tree. MORT involves two items: a diagram and a process. W. G. Johnson created the first MORT program in 1971 in the Department of Energy.

As a program, MORT helps prevent safety-related oversights, errors, and omissions. It attempts to identify and assess risks associated with an operation. Then risks get referred to the proper management level for action. MORT programs help optimize allocation of funds for safety programs and hazard control. MORT incorporates behavioral, organizational, and analytical sciences in a systematic way for dealing with energy transfer, error, change, and risk in a systematic way.

MORT involves a diagram with the process. A MORT diagram arranges safety program elements in an orderly and logical manner. MORT diagrams structure safety literature and practices into three levels of relationships. At the top level, MORT identifies 98 generic problems or *undesirable events*. At the second level there are 1,500 possible causes, termed *basic events*, for these problems. At the third level are thousands of *criteria* (standards, codes, practices, etc.). The criteria help judge whether an organization performs steps in a safety program well or are less than adequate (LTA).

Some use MORT to investigate accidents or evaluate safety programs. A MORT diagram is an idealized safety system model that uses the logic of fault tree analysis. MORT assumes that in a *perfect* safety system, all components function in a manner that contributes to or complements the achievement of tasks. A safety system or program is a process of eliminating or controlling hazardous events through engineering, design, education, management policy, and supervisory control of conditions and practices.

Figure 36-8 shows the general features of a MORT event tree. This example gives a flavor for MORT diagrams and analysis. There are many rules and procedures not covered here that make MORT an effective tool. In a MORT diagram, generic events are at the top. At the second tier are specific or management (S/M) oversights and omissions and assumed risks (R). Specific refers to events or factors specific to an accident. Management refers to factors in a general management system or context. At the lower tiers there are basic events, contributing factors, and controls that failed.

36-9 OTHER ANALYSES AND APPLICATIONS OF SYSTEM SAFETY

There are several other extensions of system safety analysis and techniques that make a system safety approach an effective one. Applications of system safety methods find their way into many safety problems. Some of these have less formal procedures. This section covers a few examples.

Energy Analysis

For many safety problems, it is helpful to analyze various forms of energy, transfer of energy, and release of energy. Haddon's theories about energy and control of it (see Chapter 3) closely fit energy analysis. When analyzing machines, equipment, processes, and operations, an analysis of energy can identify many hazards that need controls. Figure 36-9 provides an incomplete diagram of several forms of energy to consider during an energy analysis.

For example, a punch press has energy in the moving flywheel. During the machine operation, the energy transfers to the action of the punch. There are dangers associated with the flywheel and the punch actions that need protection. In addition, there are springs that store energy in the die or elsewhere. Brakes hold some machine parts in place during idle phases of the punch cycle. A failure of the brake could release potential energy in the weight of the elevated components. The parts could fall.

Some of these energy hazards are present while someone changes dies in the press. Thus, there is a need for a die prop to prevent potential energy from becoming kinetic energy. A motor in the press has electrical energy that is converted to mechanical energy. Unprotected electrical energy could lead to injury directly or through its transfer at the wrong time to the machine components.

Energy analysis may be helpful in identifying risks in powered systems and equipment and in establishing engineering and administrative controls. Energy analysis should be a part of lockout and tagout procedures. Here are some strategies for managing hazards of energy:

- Eliminate or minimize energy concentrations. For example, concentrations of combustibles creates large fire loads (see Chapter 16).

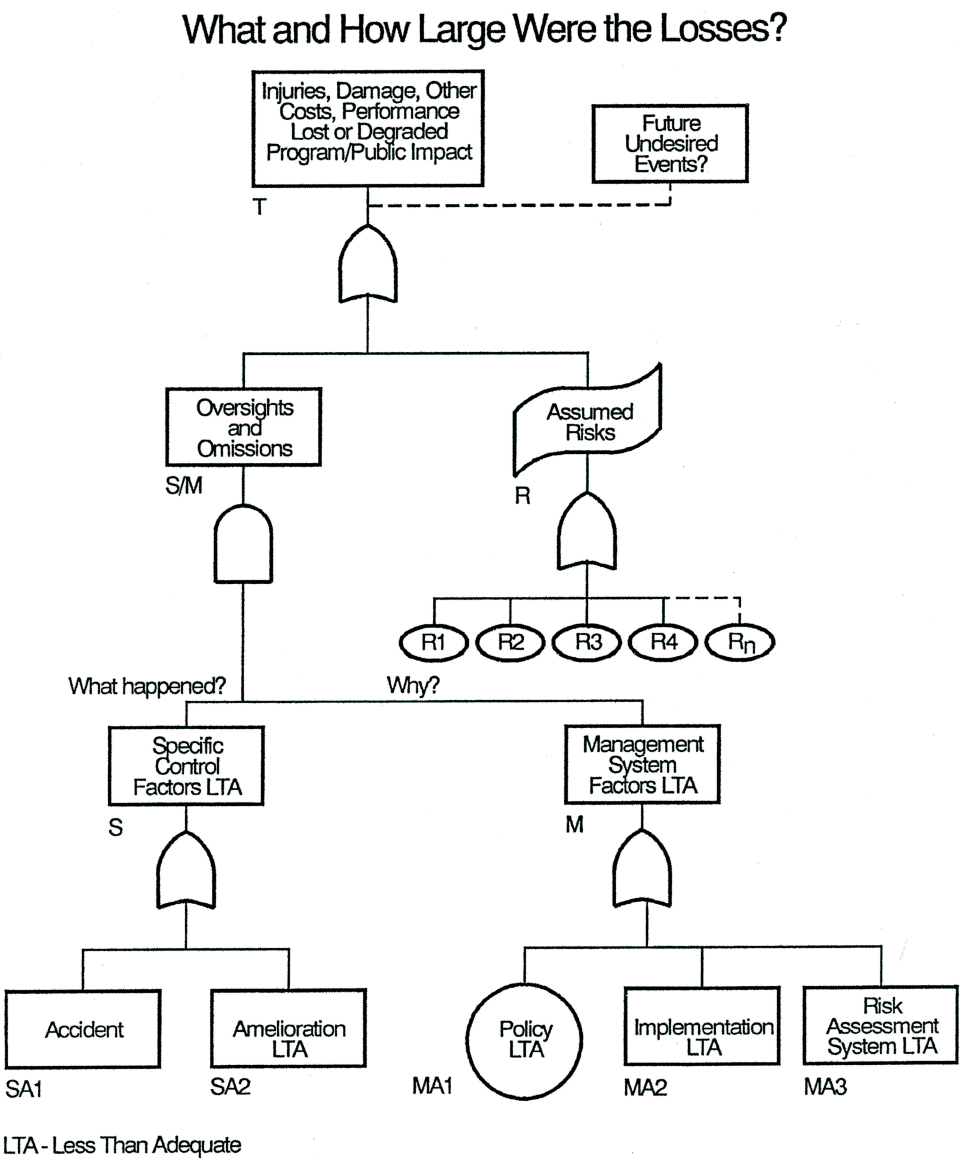


Figure 36-8. An example of the top portion of a MORT diagram. (From *MORT Users' Manual*, Revision 2, DOE 76-45/4, SSDC-4, U.S. Department of Energy, Washington, D.C., May 1983.)

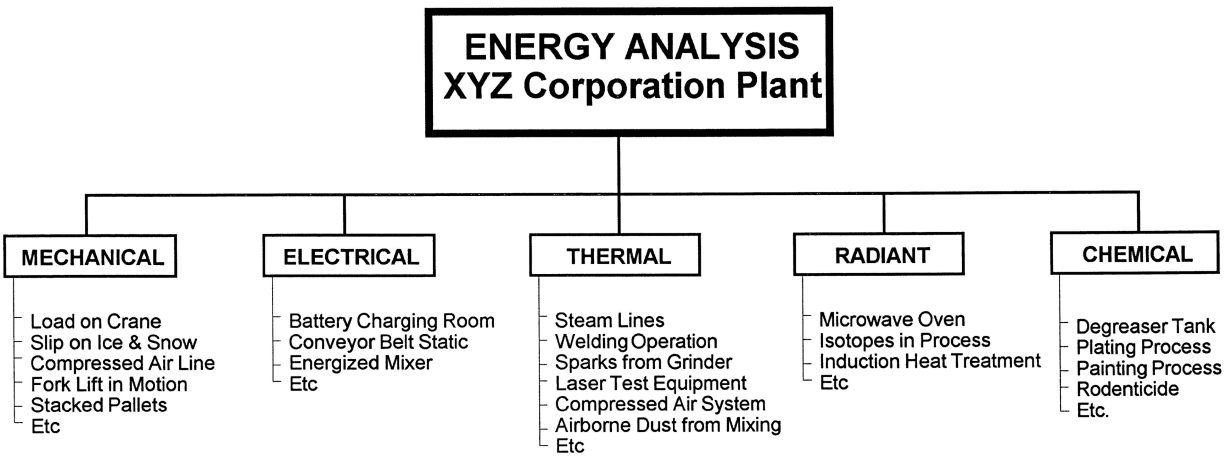


Figure 36-9. Example of an energy analysis chart.

- Limit energy quantity or energy level. An example is slower speeds for machine maintenance.
- Prevent energy releases. Lockout and tagout procedures and interlocks apply here.
- Modify the rate of energy release. Flow control in fluids and brakes are examples.
- Separate energy in space or time. An example is the application of quantity-distance standards for explosives. Another is separating pedestrian traffic from vehicle traffic.
- Establish barriers. Examples are hard hats, machine guards, and highway guard rails.
- Use energy-absorbing materials. Examples are breakaway signs on highways and padded dashboards in cars.
- Make items stronger to prevent impact damage. An example is use of concrete-filled steel barriers near gas-dispensing pumps in vehicle gas stations.
- Prevent access to energy. An example is a key control on electrical panels.

Buildings

Some government organizations require or apply system safety methods for construction projects. A project may require selective use of methods. Organizations apply system safety in some construction projects. Included are the Nuclear Regulatory Commission, the Department of Defense and its service agencies, the Federal Aviation Administration and others. Some projects may simply require use of preliminary hazard analysis that leads to a site safety plan for a project. Complex facilities that integrate specialized equipment into the project may require failure mode and effects analysis or even fault tree analysis.

Fire Safety

NFPA recognized that a building and its fire safety could benefit from a system analysis. A structure is a system made up of many components. Buildings and structures get modified over time. Their conditions often change. Codes and

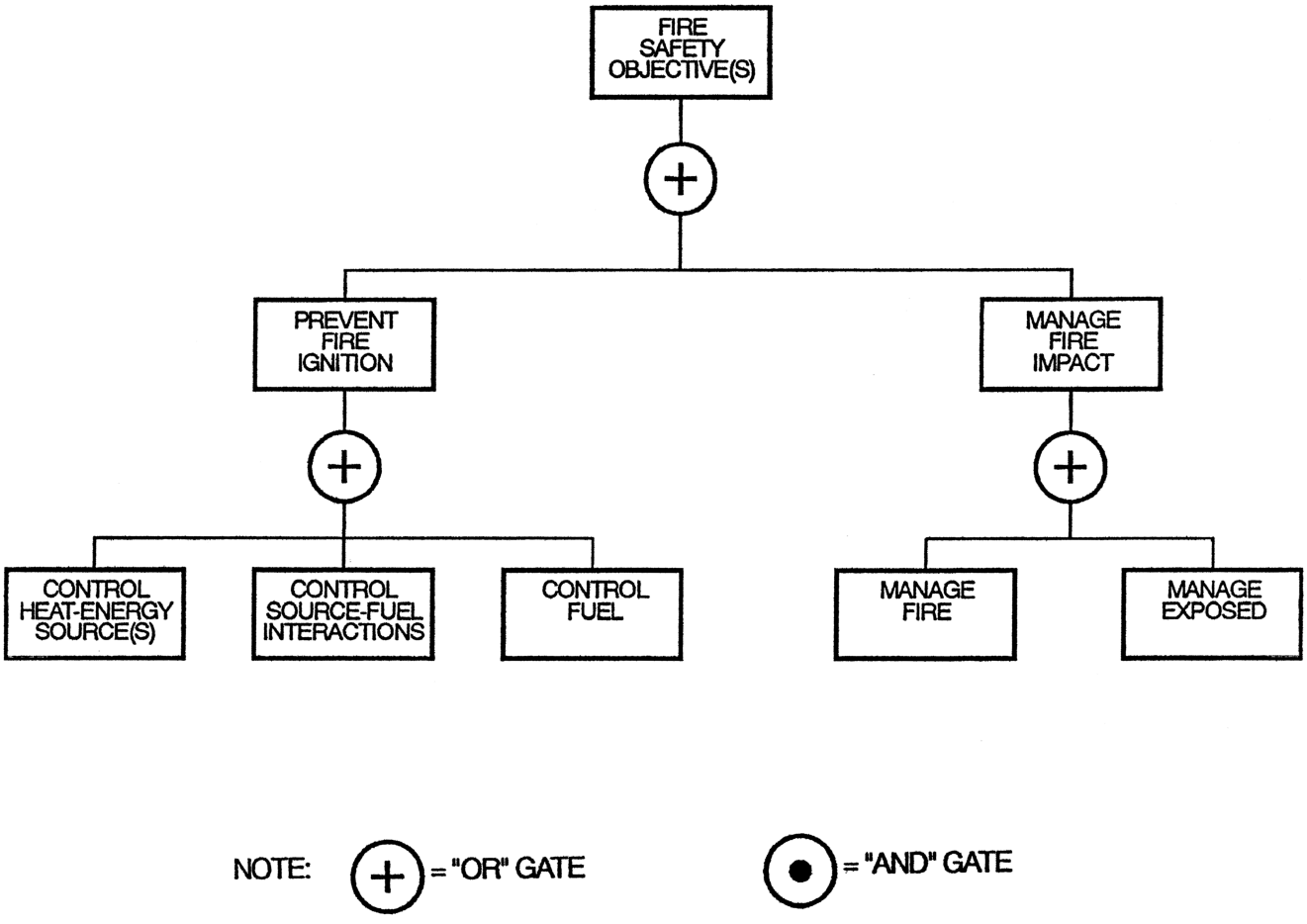


Figure 36-10. Upper levels of the fire safety concepts tree. (Reprinted with permission from the *Fire Protection Handbook*. 19th ed., 2003, National Fire Protection Association, Quincy, MA, 02169.)

standards for fire safety also change with time. A systems approach for analyzing the fire safety of a building can help identify deficiencies and pinpoint corrective actions. The process helps keep fire protection current.

NFPA has developed a *Fire Safety Concepts Tree*.[11] At the top of the tree are fire safety objectives, followed by actions to achieve the objectives. Elements of the tree connect using AND and OR gates, similar to fault tree analysis (Figure 36-10). A Fire Safety Concepts Tree can help analyze buildings and designs using qualitative and quantitative procedures.

EXERCISES

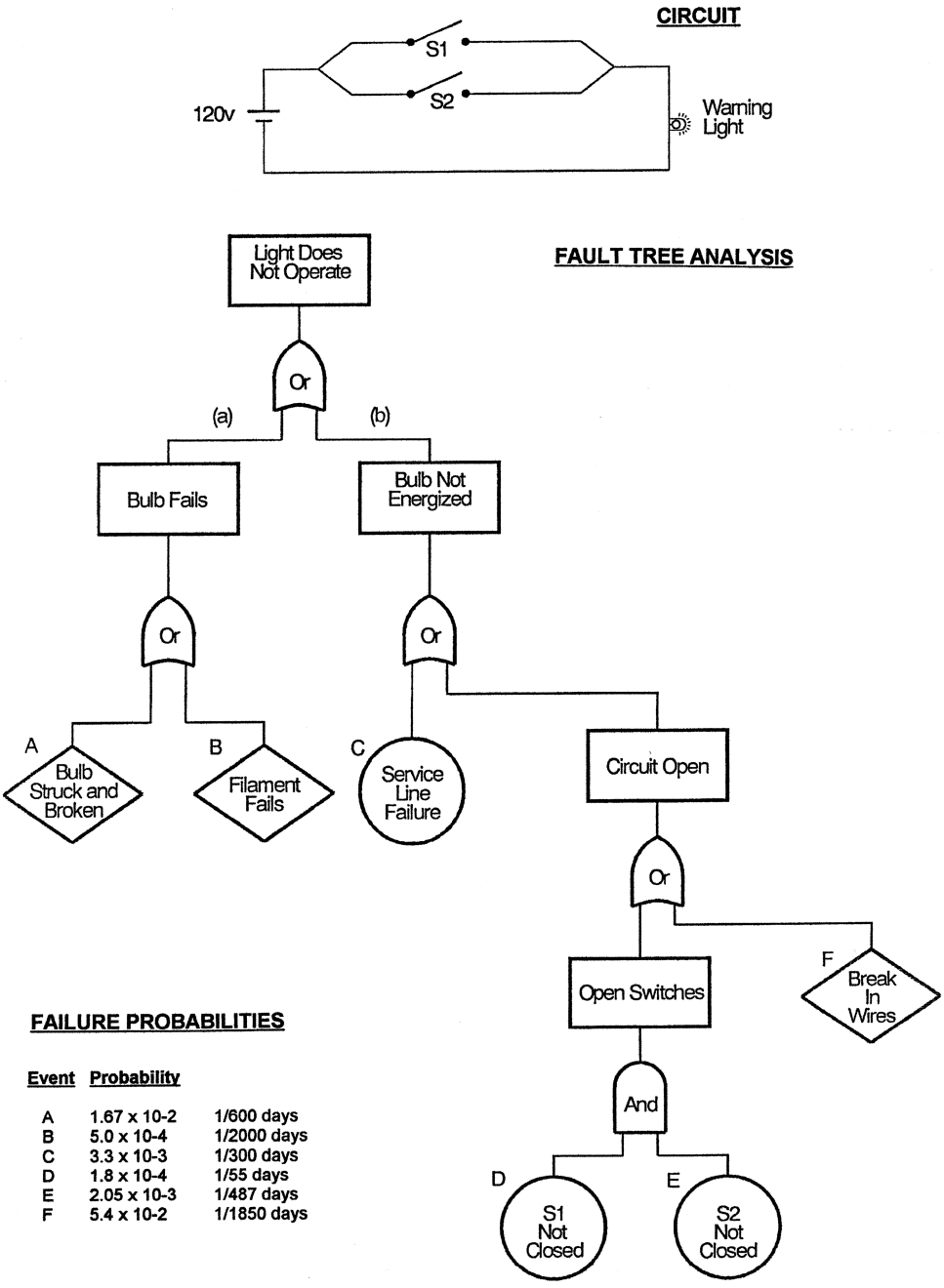
1. The circuit, fault tree and probabilities of events in a fault tree are shown in the figure labeled Exercise 36-1.

Compute the failure rates for branches (a) and (b).

Compute the failure rate for the top event.

Which branch is more critical (more likely to cause failure)?

Which failure or fault is most likely to cause the system to fail?



Exercise 36-1. System and Fault Tree Diagrams for Exercise 36-1.

2. Obtain a copy of a fault tree analysis for a system and review the analysis and results. You might wish to look at one of the classic reports on nuclear power plant safety: *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, Report WASH-1400, U.S. Nuclear Regulatory Commission, October 1975. (This report is also known as the Rasmussen report.)

REVIEW QUESTIONS

1. What is system safety?
2. Where did system safety originate?
3. What system safety procedures does OSHA include in its process safety standard?
4. What military standard documents the general procedures for system safety?
5. Briefly explain a system safety program and its objectives.
6. Identify the precedence for meeting system safety requirements.
7. Describe the PHA procedure.
8. What is fault tree analysis? What does this method analyze?
9. Identify limitations of fault tree analysis.
10. What symbol represents each of the following fault tree analysis factors?
    - **(a)** a basic event
    - **(b)** an undeveloped event
    - **(c)** a normal event
    - **(d)** AND logic gate
    - **(e)** OR logic gate
    - **(f)** inhibit logic gate
    - **(g)** a transfer or discontinuity in a fault tree diagram
11. What is the difference between a fault and a failure?
12. What are the four classes of causal events in fault trees?
13. What kinds of analyses can be performed on a fault tree?
14. What is a cut set?
15. What is FMEA? What does this method analyze?
16. Explain Root Cause Analysis.
17. What is the Hazard Totem Pole? Explain how it works.
18. What is MORT? What is this method used for?
19. Explain energy analysis.
20. Explain the Fire Safety Concepts Tree method.

NOTES

1 29 CFR 1910.119, Process safety management of highly hazardous chemicals. www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760

2 *Process Safety Management*. www.osha.gov/Publications/osha3132.html

3 *Standard Practice for System Safety*, MIL-STD 882E, Department of Defense, 2012. www.system-safety.org/Documents/MIL-STD-882E.pdf

4 *Joint Software Systems Safety Engineering Handbook*, Department of Defense, 2010. www.acq.osd.mil/se/docs/Joint-SW-Systems-Safety-Engineering-Handbook.pdf

5 *NASA System Safety Handbook, Volume 1. System Safety Framework and Concepts for Implementation*, NASA/SP-2010-580, November 2011. www.hq.nasa.gov/office/codeq/doctree/NASASP2010580.pdf

6 *Fault Tree Handbook*, Nuclear Regulatory Commission, NUREG-0492, January 1981. www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0492/sr0492.pdf

7 *System Safety and Risk Management: NIOSH Instructional Module*, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, NIOSH, March 1998. www.cdc.gov/niosh/docs/96-37768/pdfs/96-37768.pdf

8 J. L. Recht, "Systems Safety Analysis: The Fault Tree," *National Safety News*, 93, 37–40 (1966).

9 http://asq.org/learn-about-quality/cause-analysis-tools/overview/fishbone.html

10 V. L. Grose, *Managing Risk: Systematic Loss Prevention for Executives*, Prentice-Hall, Englewood Cliffs, NJ, 1988.

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CHAPTER 37

SAFETY ANALYSES AND MANAGEMENT INFORMATION

37-1 ROLE OF ANALYSIS

Converting Data into Useful Forms

Safety performance begins with data. Data may originate with incidents and accidents. It may come from measurements using instruments. Data may come from studies of operations, behaviors and other sources. Data themselves have limited value. Data need conversion to information that workers, managers, executives, and others in charge of safety and health prevention find useful. Analysis helps make those conversions.

Data, information and knowledge or insights are different, but interrelated. Figure 37-1 illustrates the logical flow of data to information, knowledge and insights.

Data are unprocessed facts and figures. In safety, data are accident and injury records, responses from surveys, attendance at training sessions, absentee records, costs, and many other items.

Information results from processed and interpreted data. Information gives meaning and understanding to data. Information makes data useful. Information is the message communicated from processed data. In safety, information is the result of analysis.

Knowledge combines information and experience for the potential benefit of an individual or an organization. In safety, knowledge allows someone to apply the information gained from data and analysis.

Insight is understanding resulting from data, information and knowledge. Insight fosters making good decisions. In safety, insight is making decisions to improve safety and offering recommendations for improving safety performance.

Purposes for Analysis

There are several places in this book that recommend analysis. The preceding two chapters in particular reviewed some of the more prominent analytical procedures frequently used in safety. This chapter will consider a few more. Analysis can be expensive. It may consume many hours of work by many people. As a result, it is important to consider the amount of analysis needed and the purposes for analysis.

Sometimes people continue with analysis to the point where any further information or results have no value. In some cases, analysis continues because an organization has always done it. In safety, analysis helps managers solve the problem: "How safe is safe enough?" See Figure 3-5. Performing analysis for its own sake may be interesting for some but may not be justified by the value and usefulness of the results.

Understanding One purpose for analysis is to gain understanding. It is not always obvious how activities and processes work or what causes failures or accidents and incidents. Carefully defining the components or elements involved in a process and identifying the relationships among them will help provide insights. The results of this kind of analysis can provide understanding of complexities. Analysis makes it possible to discover and observe the intricate relationships among people, their work, and their workplace. The need to gain understanding appeals to the human urge to explore.

Trends Another purpose for analysis is identifying trends. If a goal is reducing the number or rate of accidents, there is a need for analysis. Analysis will show if the number or rate of accidents is increasing or decreasing. Analysis will show if a hazardous environment is improving or getting worse.

Making Decisions Another purpose for analysis is making decisions. Analysis may help managers select the correct action or course of action. Financial analysis may help managers allocate funds. Studies of productivity may help managers decide on assigning people, equipment, or other resources to improve. Decision-making is a primary reason for analysis.

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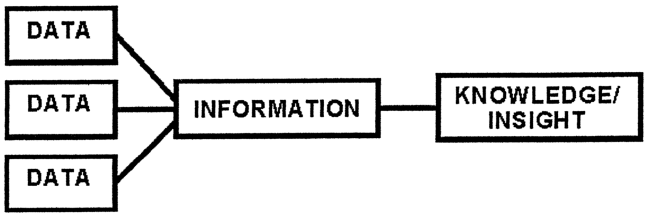


Figure 37-1. Data must be converted into information and information into knowledge and insight.

Meeting Requirements An additional reason for performing analysis is to comply with requirements. Many times laws, regulations, or contracts require people to complete analysis. Someone else may use the information and results in decision-making. For example, when someone has a sizeable automobile accident, the vehicle owners must perform enough analysis to prepare a report. In some cases, attending police officers must collect evidence and analyze it to determine whether to file charges against vehicle drivers or others. Some design contracts require that performance of certain analysis to aid others involved in the design project, production, or use of items under designed.

Accident Prevention From a safety point of view, a primary purpose of analysis is to prevent accidents. It is important to communicate with managers and explain what hazards exist and what controls to implement. Analysis may help determine if one can eliminate or reduce hazards at a reasonable cost. Analysis may help determine if controls are effective and provide the benefits anticipated.

37-2 INSPECTIONS

Inspections are a common form of analysis intended to prevent accidents. It is possible to chart failures of a process or system. When operating systems, inspections can detect actual faults and failures in equipment, activities and workplaces. Inspections are part of a proactive approach to accident prevention (see Figure 3-6).

Types of Inspections

General and Specific Inspections There are two main kinds of inspections: general and detailed. In a general inspection, individuals or teams look for a wide range of deficiencies. Figure 37-2 illustrates a checklist useful in a general safety inspection. General inspections can cover many topics. They can be very precise and rely on detailed checklists.

Aircraft pilots must learn to conduct a general inspection of their aircraft before every flight. They walk around the aircraft looking for any unusual conditions that could affect the airworthiness of the airplane and its flight safety. When working for some airlines, a pre-flight inspection relies on a checklist to assure that all important items get checked.

There are also detailed inspections, tailored to the activity and equipment involved. In detailed inspection, people look for very specific conditions. For example, a rigging inspector for a crane must have skills to identify about 20 kinds of defects in wire rope. Some defects are easy to recognize. Others are difficult. They require special training and considerable experience.

Some aircraft inspections are very detailed, requiring several days to complete. For example, the inspection may require removing panels to inspect structural elements.

OSHA inspections are general or targeted. In a general inspection, inspectors look for any non-compliance with OSHA regulations. In a targeted inspection, they look for specific types of non-compliance only.

Scheduled and Unscheduled Inspections There are also scheduled and unscheduled inspections. Scheduled inspections are those required regularly. A clock or calendar may governed the schedule. An example is a daily inspection of equipment at the beginning of the shift. Other inspection schedules rely on hours of use or the number of use cycles since the previous inspection. Specialists inspect aircraft after a certain number of flight hours. A cycle-derived inspection is the pre-flight inspection by the pilots and ground crew before every flight. Some inspections occur around events. A person operating a tool crib inspects tools every time just prior to issuing them to a user. The person also inspects them upon their return. A field engineer may inspect a product while making a troubleshooting visit to a customer.

Unscheduled inspections may be random visits by specialists. Unscheduled inspections may occur when someone brings equipment in for maintenance or repair. During the repair visit, someone checks the equipment for other deficiencies and hazardous conditions, not only the components involved in the repair.

A good time for a general inspection of a plant is when it is down for maintenance or during installation of new equipment. Another good time is during closure of a shift because of low product demand. Railroad companies teach workers to inspect all passing trains for shifted loads, bearing and wheel failures, and other kinds of problems.

Inspectors

Who is an appropriate inspector? Who can identify hazardous and defective conditions? There are several strategies that apply when deciding on inspectors. In some cases, detailed training, knowledge, and experience are necessary to recognize a problem. In other cases, nearly anyone can learn to identify unsafe conditions. Some inspections may

GENERAL SAFETY INSPECTION WORKSHEET			
TOPIC	**HAZARDOUS CONDITIONS**	**OBSERVATIONS**	**CONCLUSIONS & RECOMMENDATIONS**
Machines & Power Transmission Equipment	• Guards in place & good condition • Unguarded dangers • Controls - Clearly identified & coded - prevent unintended activation - emergency stops near workers • Power transmission items guarded • Energized equipment lock-out capable		
Hand Tools & Portable Power Tools	• Proper tools available • Tools in good condition • Power tools grounded or insulated • Gas powered equipment vented		
Manual Materials Handling	• Proper lifting methods known and followed • Lifting minimized through ergonomic lifting devices • Materials handling boxes, totes, skids, pallets, etc. in good condition • Hand trucks adequate and in good condition		
Industrial Vehicles	• Have the right capacity and suitable for materials handled • In good condition • Overhead protection in place • Seat belts in place and used • Traffic aisles clearly marked • Blind spots have mirrors • Operators properly trained		
Work Environment Conditions	• Presence of noise, chemicals, dust, vapors, fumes, & heat or cold • Ventilation hoods and systems operating properly • Heat and cold environments managed properly • Chemical exposures known • Adequate PPE • MSDSs available where applicable		
Floors & Floor Openings	• Floors free of tripping, slipping and other hazards • Floor & wall openings protected		
Ladders, Scaffolds & Stairs	• In good condition • Properly positioned and supported • Stairs free of materials • Handrails in place and anchored		

Figure 37-2. Example of a general safety inspection checklist.

TOPIC	HAZARDOUS CONDITIONS	OBSERVATIONS	CONCLUSIONS & RECOMMENDATIONS
Elevated Work Equipment & Platforms	• Overhead systems have protection for falling materials • Platform edges and opening properly guarded • Platforms free of unorganized materials & adequate walk/stand areas		
Hoisting Equipment & Elevators	• Regular inspections completed and recorded • In good operational condition • Suitable of objects lifted • Rigging is proper • Proper training in operation		
Electrical Equipment	• Wiring clear of people and operations and enclosed in conduit • Equipment properly closed and locked • Free of flammables & combustibles • Power cords are free of defects • Power cords used properly • Proper grounding and bonding in place • Free of wet standing area or other hazards • Proper PPE issued and in use		
Heat and Steam Equipment	• Regular inspections completed and recorded • Lock out/tag out procedures in use • Steam lines isolated or de-energized for work		
Pressurized Equipment	• Gas cylinders properly marked, stored and handled • Overpressure devices in place and operational • Training and safety procedures in place		
Fire Protection Systems	• Exits and exit routes properly marked • Exit signs lighted • Automatic doors operable • Emergency lighting operable • Extinguishers in place and operable • Alarms in place and operable • Sprinkler heads have clear space		

Figure 37-2. *Continued*

require use of special instruments and tools. Someone may need special knowledge to use them properly.

Some inspections need an independent perspective. A person performing work on an item or in a work area may have knowledge for an inspection. However, someone else may find conditions that the first worker overlooks because of familiarity with the item or location. Independent people bring a fresh perspective. They may see mistakes made by someone else.

In some cases, two inspectors are necessary. Consider inspection of completed work. The person who performed the work should be the first inspector. A co-worker,

TOPIC	HAZARDOUS CONDITIONS	OBSERVATIONS	CONCLUSIONS & RECOMMENDATIONS
Housekeeping & Storage	• Waste properly collected and organized • Floors clean • Flammable and combustible materials properly stored • Materials properly piled & stored • Adequate storage systems • Restrooms, change areas & eating areas clean and properly supplied		
First Aid Supplies and Training	• First aid supplies available • Adequate first aid supplies • Access to trained first aid person • First aid properly administered • Emergency showers and eye wash fountains in place and working properly		
Adherence to Safety Policy & Procedures	• Knowledge of safety policies • Safety information posted • Knowledge of applicable safe operating procedures		
Personal Protective Equipment	• Issued PPE worn • Issued PPE properly fit and in good condition • Knowledge of proper PPE • Correct PPE identified		
Safety Signs & Information	• Caution and warning signs in place • OSHA and other safety standards posted • MSDSs available and provided		
Safety Training	• Individual safety training identified • Regular safety issues discussed • Safety training materials available • Safety training completed		
Administrative	• Incidents and accidents reported • Safety training records maintained • Safety information, signs, training resources and procedures up to date		

Figure 37-2. *Continued*

supervisor or specialist should be the second inspector. The second inspector may be more knowledgeable and experienced. The double inspection provides redundancy.

Each situation dictates who qualifies to conduct an inspection. Inspectors can be workers, co-workers, supervisors, specialists (engineers, safety specialists and others), or special teams. In some cases, inspectors need certification for the inspections they perform. Recertification is also important to assure that inspection skills are current and meet inspection standards.

Inspection Tools

The most common tool for inspectors is a checklist. Humans are not good at remembering a long or complex list of items. A checklist helps prevent memory lapses. Humans are not good at keeping track of which details they completed. A checklist provides a means for tracking the items already inspected. A checklist may have a place to record findings. Checklists should have a place for inspectors' signatures. A signature attests to having inspected an item or the complete

list and recorded findings. Signing for someone else is a misuse of a signature block. It may be illegal.

Visual inspection is not sufficient for some items. Inspectors may need special tools or instruments to complete an inspection. Examples are air sampling instruments and analysis devices for confined space entry. There may be test instruments for assessing atmospheric pressure and light levels. Some openings on machines intended for inspections have covers requiring special tools to remove them.

Inspection Procedures

Here are a few important guidelines for completing inspections.

- Be selective. Look for particular items.
- Know what to look for. Know what failures and abnormal conditions look like.
- Use helps, such as checklists.
- Practice observing.
- Look for facts that are relevant.
- Guard against habit and familiarity. Vary the order of items. Be thorough.
- Be ready to sign that everything was checked and items are in order or problems noted.
- Record observations accurately.
- Avoid conversations and distractions that may inhibit careful inspections.
- Get additional help to verify a finding if there is any question about something not being in order.
- Continue to report faulty conditions until they get corrected.
- Make sure the inspection report gets to someone who can do something about a deficiency.

37-3 SAFETY AUDITS

Safety audits are systematic procedures for reviewing management systems and practices implemented to achieve safety. They can include a compliance review, similar to a safety inspection. The audit process also allows for reviewer suggestions and recommendations for improvement. Audits may be part of more general practices to ensure that management systems are in place and followed as written. Audits can apply to systems, processes, products, programs, or services.

The popularity of audits grew with the implementation and expanded use of quality management systems defined in ISO 9000[1] (basic concepts of quality management) and ISO 9001[2] (basic requirements for a quality management system). The ISO standards require written management systems for an organization and compliance with them. Audits by teams from outside the organization ensure that management systems meet ISO standards and an organization complies with its own internal, written documentation. The audits may lead to certification, which indicates compliance with the ISO standards.

The ISO standards also address environmental management in ISO 14000.[3] There is also a standard on occupational safety and health management that relies on the ISO 9000 philosophy and methods: BS OHSAS 18001.[4] It is likely that ISO 45001[5] will replace it.

Once an organization sets the scope of its own audit, it can decide whether internal personnel, personnel from a different facility, or a contractor will conduct the audit. The members of the audit team should have qualifications suitable to the contents of the audit. After forming an audit team, it plans the audit in detail.

The audit process typically involves the following:

- An opening meeting in which the audit team meets with senior management and reviews the process and schedule.
- Information gathering through interviews, examination of documents, observation of activities and operations.
- Documentation of observations and findings, particularly any not in compliance with written standards, policies and procedures.
- Meetings of audit team members to collaborate on audit activities, progress and findings.
- A closing meeting by the audit team with senior management to summarize the key results of the audit process.
- Preparation of a written audit report detailing the process, findings and recommendations; providing the report to senior management.
- Establishing a corrective action plan.
- Follow-up on progress in the action plan.

37-4 ACCIDENT INVESTIGATION

Another form of analysis is an accident investigation. When an accident occurs, it offers a chance to learn from it. Accident investigations are part of the reactive approach to accident prevention depicted in Figure 3-5.

Purposes

There are several purposes for investigations of accidents. A primary purpose is to prevent future accidents, especially those of a similar nature. Another purpose is to identify causes of accidents and injuries. Such information is

necessary to prevent future accidents. A third purpose is to compile legal or liability evidence. Such information has use in the event of legal claims or lawsuits for losses or injuries. For some accidents, there is a need for data to support insurance claims for injury or property damage. Another purpose is to measure costs for injury, death or equipment and property damage.

A general reason for accident investigations is gathering facts. One should use multiple factor accident theories (see Chapter 3) in an accident investigation. The approach helps prevent overlooking important information. Seldom do accident investigations have the purpose of placing blame or finding fault. When they do, it is for legal purposes and insurance claims in a fault-based claim process.

Types of Investigations

There are two main types of investigations: general and special. One can divide special investigations into many additional categories.

General General accident investigations are typical of investigations related to most in-plant accidents. A supervisor may look into causes and prepare a report. In some cases, specialists within the organization may participate in the investigations. Some procedures are generic and do not involve special methods and instruments. General investigations use interviews to gain first-hand accounts of what happened. Most use visual observations to gather information from the accident scene. Investigators interview witnesses of the accident or post-accident events. Investigations may include a meeting of all witnesses to discuss potential causes and corrective actions. Company investigation forms may define major types of data to collect. Investigators may capture photographs to include with a written report. With the prominence of photo capabilities in smart phones, most people have the ability to capture photos or even video information.

Special Special accident investigations are those that require particular knowledge and skill of investigators. Particular kinds of accidents and incidents require specialized investigators. For example, there are fire investigators trained and equipped to gain information following fires. There are special investigators and methods for aviation accidents, train accidents, and automobile accidents. During the 1980s there was a national investigating team for elevator explosions. Special investigations often require particular tools, instruments, and procedures. For example, fire inspectors need to have kits for taking samples to test for the presence of flammable materials. In some cases inspectors must avoid certain procedures. For example they must avoid contamination of samples. Case 35-1 and Case 36-1 involved special accident investigation teams.

Which Accidents to Investigate

It may be too expensive to investigate all accidents. It may be too expensive to bring in specialists for every accident. It may be costly to compile a lot of data and perform physical, chemical or computational analyses. The following criteria help with decisions about which accidents to investigate.

High Cost and High Severity Accidents with death, significant injuries, and high property losses require investigations. In fact, several parties will probably conduct independent investigations of the same accident. Each will have liability and legal interests. Some will represent the employer or owner. Some will represent insurance companies. Some will represent victims. When there are high losses, there will be arguments over who should pay for the losses.

High Frequency There should be investigations for high frequency accidents. A goal is to uncover similarities and patterns among cases. The information may lead to important preventive actions. An investigation may detect a pattern of events and causes. The trend may appear from accident and incident reports. They may arise from customer claims or complaints, from field reports, or from repair or work orders. Another goal is to identify differences among similar accidents. Looking for differences may lead to insights on causes and contributing factors.

High Public Interest Accidents that gain much public attention need investigations. For either a company or public official, there is a need to deal with public concerns. High public interest cases require skillful communication to the public. One goal is to provide facts to reduce speculation. Also, there is a need to preserve a company or organizational image by conducting an investigation and providing information to the public.

High Potential Losses Incidents that produce limited injury or damage, but could have led to large losses of property or human life need investigations. There is a high potential for preventing such losses in future accidents.

Investigation Tools and Data

Some of the basic tools for accident investigations are rope or security tape to secure the area and keep the curious out. Imprinted tape will help keep the curious from damaging or removing evidence. Investigators need to use note and sketch pads. They need photo and video capabilities. Some evidence has a short life and making visual records early is important. Investigators need audio or video equipment to capture witness interviews.

Special instruments may be important, depending on the kind of accident involved. For radiation releases, Geiger counters or similar instruments are essential to gain readings

of exposures. For chemical spills, there may be a need for colorimeters, direct reading instruments for particular chemicals, and other sampling equipment. Investigators need uncontaminated containers for specimens of various types. They need identification tags for marking evidence and samples. They need tape measures or other distance measuring devices to establish accurately the location of items at an accident scene. In automobile accidents, for example, it is critical to capture location data for vehicles, tire marks, and other accident scene items.

The law may dictate what data to collect. For example, in certain automobile accidents police officers must acquire information on alcohol and drunkenness. These are some general kinds of data to collect during investigations. Some data is unique to particular kinds of accidents.

There are standards and guidelines for the data needed in particular kinds of investigations. Photographs and sketches of physical conditions, the surround, and damages are important. Video data may be important if the occurrence lingers. Investigators must compile witness statements accurately. Tape and video recordings, even those from security cameras, and transcripts can help achieve data accuracy. Key information includes where people were, when they were there, and what they saw or heard. Investigators may collect specimens and samples of various kinds. They may use instruments to record data on environmental or other conditions. They may collect damaged equipment or parts. They need to collect data on injuries.

When to Investigate

The best time to investigate an accident is as soon after the occurrence as possible. Data and evidence begin to disappear or deteriorate with time. Witness recollections also deteriorate with time. Important details may become lost if there are delays in investigations.

Investigation Methods and Procedures

There are a few references on accident investigations. Figure 37-3 shows the classical steps in accident investigation.

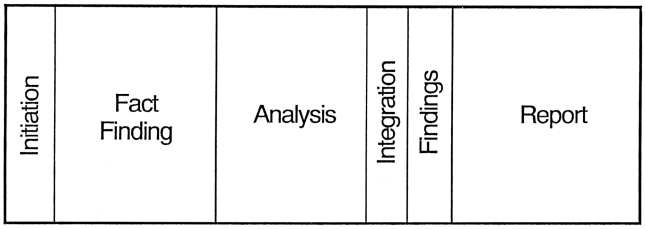


Figure 37-3. Classic steps in accident investigation. (From *Accident/Incident Investigation Manual*, 2nd Edition, DOE/SSDC 76-45/27, SSDC 27, U.S. Department of Energy, Washington, DC, November 1985.)

In reality, the steps do not occur one at a time. Several steps may overlap and occur at the same time. Figure 37-4 is a general flow chart of accident investigation procedures. Figure 37-5 is an expanded process for the investigative phase.

Analyzing Investigation Data and Reporting Results

Analysis is a critical part of the investigation process. There are many different methods to use. Some methods are general and valuable to the accident analysis process. Examples are fault tree analysis, root cause analysis, and management oversight and risk tree (MORT) analysis. For automobile cases, there are accident reconstruction computer tools. There are also computer tools for reconstructing fire behavior in buildings and estimating exiting behavior of people.

The analysis leads to findings and conclusions. Written reports should identify the procedures used, participants, data compiled, analysis and results of analysis, findings, and conclusions. A report should also have recommendations for preventing such incidents in the future.

Applying Findings

It is not sufficient to end an investigation with a report. The report needs to get to managers, public officials or others who can do something about the recommendations provided in an investigation report. Recommendations should lead to engineering and design changes, procedural changes, changes in policies, rules or regulations, improved training, and other actions.

37-5 SAFETY PERFORMANCE

Analysis results may show significant savings or other benefits and justify management approval for safety programs. With approval and allocation of funds, changes can move forward to reduce hazards and losses. An additional step is finding out if the changes lead to the estimated improvements in safety performance. There are many techniques to determine the effectiveness of safety programs. Some approaches are statistical. Some are empirical. Some are objective. Some are subjective. Each method has value for particular situations. Manuele[6] reviews a variety of approaches. This discussion will cover a few. Others methods, such as risk analysis, inspections and audits, when used again may determine what level of improvement safety actions achieved[7].

Chapter 35 discussed differences between leading and trailing safety performance indicators.

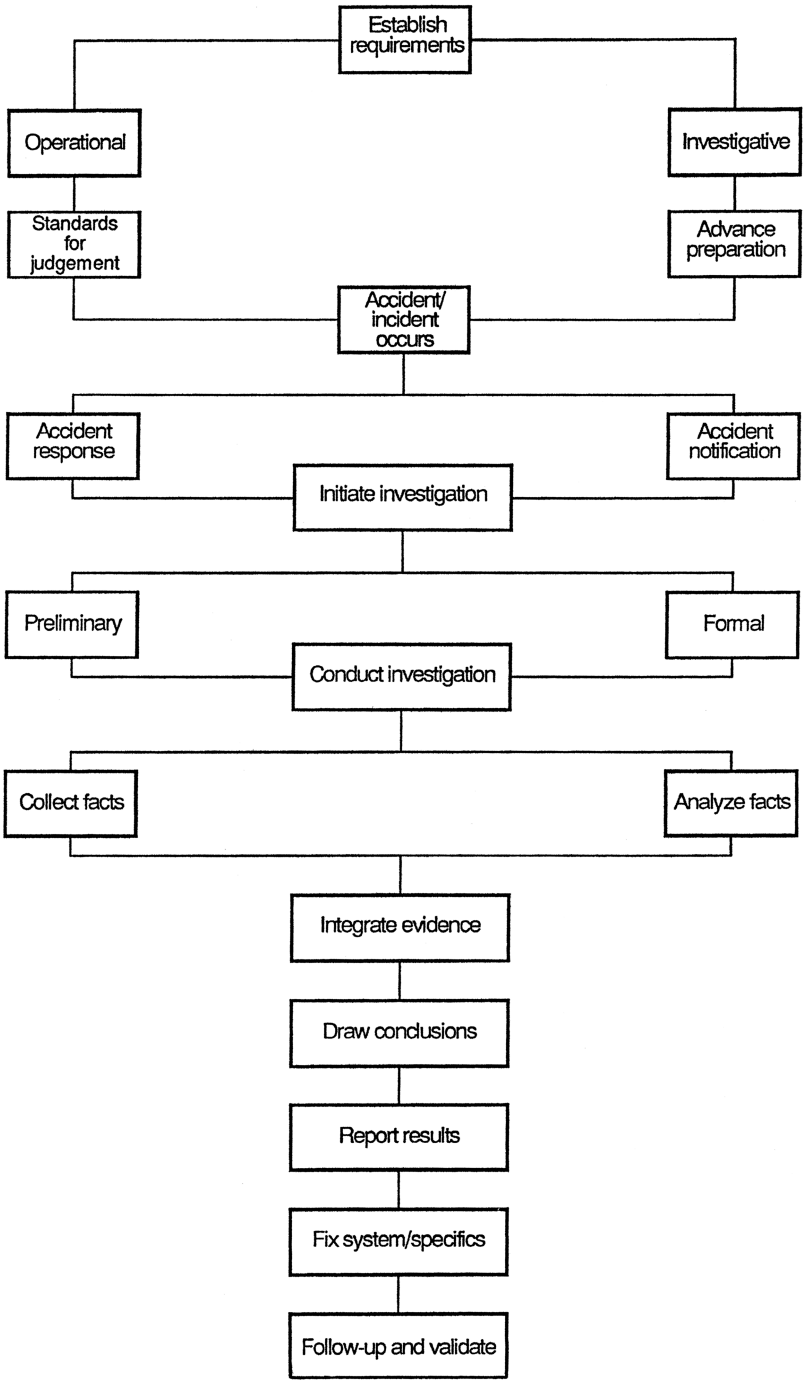


Figure 37-4. Flow chart of accident investigation procedures. (From *Accident/Incident Investigation Manual*, 2nd Edition, DOE/SSDC 76-45/27, SSDC 27, U.S. Department of Energy, Washington, DC, November 1985.)

Statistical Approaches

Accident Statistics Chapter 8 covered record keeping and some accident statistics. The most common statistics are weekly, monthly or annual accident or incident occurrences. They usually include frequency and severity statistics. These general statistics give an overall picture of an organization's safety performance. An organization may compare its performance to statistics for its industry group or similar types of business. Frequency rates and some other statistics are available for particular industries from the National Safety Council,[8] from the Bureau of Labor Statistics,[9] and from insurance companies offering workers' compensation insurance.

Although accident and injury statistics help measure performance at a broad level, they may not be sensitive

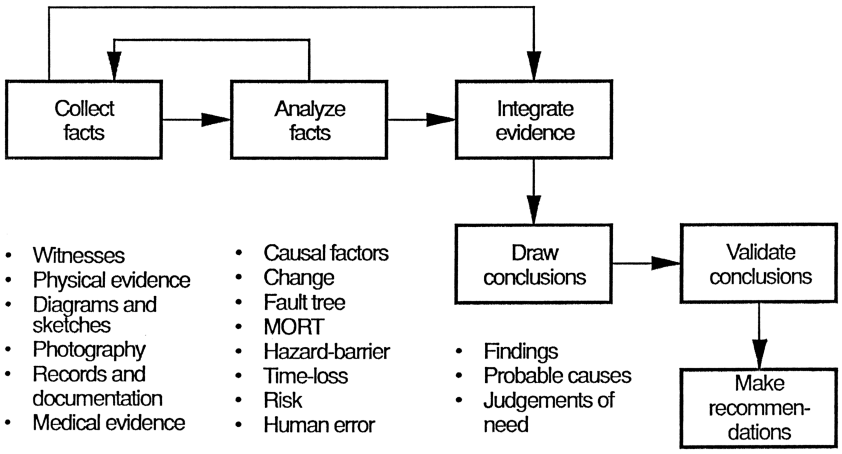


Figure 37-5. The accident investigation process.

enough for use in individual departments or small organizations. There are not enough cases in a month or year to draw conclusions about safety performance. A single case may distort the total picture. There may be other trailing indicators available. For products, a company may rely on customer claims, cost and other data.

That is why leading indicators may be more useful in measuring safety performance. Refer to Chapter 35.

Beside counts of cases or severity of incidents, other statistical methods may help determine if a safety program has affected accident or incident performance. Refer to a standard textbook on inferential statistics. For example, one can compare the mean accident rate for six months before program implementation to a six-month period after the program begins.

One may have sufficient data to apply multivariate analysis. For example, multiple regression analysis may identify the extent to which key dependent factors contribute to accidents, the independent variable. Use of that method may help identify which elements of a program have the greatest impact on safety performance. The methods may also work for leading indicators of safety performance.

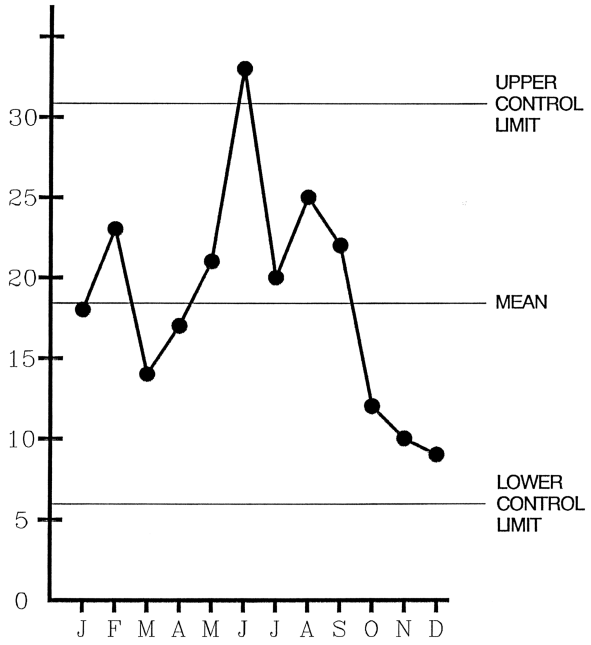


Figure 37-6. Accident control chart.

Control Charts When sampling events, there is random variation in events in sampling periods. For example, the number of accidents for a company will vary each month. A problem is knowing whether the variation is strictly random or whether some program or control has produced desired results. Control charts help answer that question.

Figure 37-6 illustrates the idea of a control chart. An analyst plots the number of accidents per month for a company over a two-year, twenty-four-month period. Horizontal lines represent upper and lower bounds compared to the mean number of accidents per month for the two years. There is an upper control limit and a lower control limit. The limits represent 95% (two standard deviations from the mean) or 99% (three standard deviations from the mean) deviations above or below the mean. If the number of accidents for one month falls outside either boundary lines, the variation is most likely due to something other than random effects. Such a deviation indicates a real change in performance. The change may be the result of a safety program if a monthly number is below the lower control limit. Other factors may drive it above the upper control limit. If there are enough monthly cases and one has both a mean accident frequency and a standard deviation for the data, then one can compute the upper control limit, UCL

$$\text{UCL} = x + z_{0.025}\, S \qquad (37\text{-}1)$$

where

x is the mean frequency
z is the standard normal distribution for the normal curve at the 0.025 probability level
S is the standard deviation for the population

and the lower control limit (LCL) can be computed from

$$\text{LCL} = x - z_{0.025}\, S \tag{37-2}$$

Example 37-1 An organization compiled accident frequency data for 12 months and wants to establish a control chart for the data. The number of accidents for each of 12 months are: 18, 23, 14, 17, 21, 33, 20, 25, 22, 12, 10 and 9. The mean is 18.67 and the standard deviation is 6.57. From a table of z values for a 0.025 probability level, $z = 1.96$. Then UCL and LCL are

$$\text{UCL} = 18.42 + 1.96(6.34) = 31.55$$
$$\text{LCL} = 18.42 - 1.96(6.34) = 5.79$$

The results are those shown in Figure 37-6. From the control chart, one can see that only one of the months was outside the control limits, though there was considerable variation in frequencies during the 12 months.

The accurate use of control charts depends on the distribution of data being similar to the statistical normal distribution. Statistical assumptions are not valid unless there is a sufficient sample size (accident cases per month) and there are factors that cause a sudden change in data. To assure a control chart's validity, there should be about 60 sampling periods (typically months).

In addition, if there is a sudden change in conditions (such as the number of employee changes, a major change in a safety program, etc.), there is a need for a new basis for computing a control chart. In Example 37-1, the last three months appear to show a significant change in accident frequency. One should look further at the trend. If a special promotion were underway, the change might be a result. In that case, the last three months may become the start for a new control chart.

Some may use control charts for evaluating safe behavior.[10] The procedures involve use of work sampling techniques. The study could evaluate the effect of a safety program on errors or unsafe behaviors. A series of observations before the program starts could establish a background for the evaluation. One would record observations during a sampling period using random sampling. The observations may monitor unsafe operating procedures. A company may introduce a safety program focused on completing operating procedures safely. The background period forms a basis for judging the program effectiveness. If the unsafe behaviors decreased and fell below the LCL, one could conclude that the program had the right impact.

The computation of control limits for proportions is

$$\text{UCL} = p + 1.96[p(1-p)/n]^{0.5} \tag{37-3}$$

$$\text{LCL} = p - 1.96[p(1-p)/n]^{0.5} \tag{37-4}$$

where

p is the mean proportion of observed behaviors that are unsafe or safe for all observation periods
n is the number of observation periods

The number of readings, N, required for a certain level of accuracy at a 95% confidence level is

$$\text{N} = 4(1-p)/S^2 p \tag{37-5}$$

where

p is the proportion of safe or unsafe acts observed during the study
S is the desired accuracy (percent per 100 readings)

The accuracy of readings is the proportion observed plus or minus some percent of accuracy. For example, one might report the average portion of observed unsafe behaviors across observation periods is $18\% \pm 3\%$.

Example 37-2 A study wishes to determine how often workers at 14 workstations involving similar tasks made errors that could lead to accidents. If the error rate is excessive, the data would serve as a baseline for a corrective program. The study must determine the baseline within 15% accuracy of the real behavior. How many work cycles (observations) must the analysis include to achieve this accuracy at a 95% confidence level? A preliminary study found a 24% error rate.

The number of observations required is

$$\text{N} = 4(1 - 0.24)/(0.15)^2(0.24) = 563 \text{ observations}$$

which amounts to $563/14 = 40$ observations per workstation.

Subjective Methods

Rating and Attitude Scales Another approach used by some organizations is to use validated attitude questionnaires, which may be given to managers and workers. Various scales built into the surveys assess the attitudes and opinions toward safety and safe behavior. The results may be useful in determining if safety programs change management's and workers' views toward safety and potential behavior.

Judging During safety audits and other evaluation processes, one or more persons may make subjective judgments

	Points	
	Possible	Earned
1. Statistical Analysis	**20**	
A. Incidence rate for pervious fiscal year	10	
B. Workers compensation claim costs in relation to standard premium	10	
2. Inspection for Compliance with Safety Standards	**15**	
A. Material handling and storage B. Machine guarding, interlocks and controls C. Health and hygiene D. Fire protection E. Other standards	15	
3. Risk Analysis	**25**	
4. Line Management Support	**10**	
A. Top management	5	
B. First Line supervision	5	
5. Safety Program	**30**	
A. Inspections	5	
B. Training	5	
C. Safety coordinator function	10	
D. Safety promotion	5	
E. Safety committee	5	
TOTAL	**100**	

Figure 37-7. An example of a form used in evaluating a safety program. (Reprinted with permission from C. J. Brigham, "Safety Program Evaluation: One Corporation's Approach," *Professional Safety*, May:31-34 (1981), official publication of the American Society of Safety Engineering. Form from Rexnord, Inc.)

about particular aspects of a safety program. Comments logged for items in an inspection checklist may be subjective judgments. The judgments may alert specialists to perform a more detailed evaluation.

Combinations of Methods

Any single method may not be adequate for evaluating the effectiveness of safety programs. The range of details may be too broad for one measure. Different measures may be suitable for accidents, injuries, illnesses, work conditions, risks, attitudes, behaviors, knowledge of workers, management support, and compliance with safety standards and company rules. Some companies devised their own evaluation system that uses several different measures. Assessment may become more difficult if different organizational units have very different operations and hazards.

Figure 37-7 is one example of an evaluation form.[11] It is a type of safety report card for major organizational units. It uses a point system distributed over five major evaluation areas. Most areas have several elements. Table 37-1 identifies points for statistical analysis derived from guidance for raters. Other sources provide guidance for compiling and analyzing data.[12]

37-6 PRESENTING RESULTS OF ANALYSES

After completing results from safety analyses, the result usually go to managers and others for decision-making, training and other purposes to improve safety performance. Methods for presenting results influence their communication effectiveness.

Computer software makes it easy to convert numerical data into various tables and charts. Some software offers ways to create three-dimensional graphs and charts. Tables are better than graphs for presenting precise data and complex sets of data.

If trends are important, line and bar graph make trends visual. Figure 37-8 gives an example of each. Pie charts effectively communicate distributions of elements that make up a total. Figure 37-9 gives an example of a pie chart.

TABLE 37-1 Guidelines for Scoring Certain Elements of Safety Analysis and Evaluation (shown in Figure 37-7)

Incident Rate Based on No. of OSHA Lost Workday Cases	Points
0.0	10
0.1–0.5	9
0.6–1.0	8
1.1–1.5	7
1.6–2.0	6
2.1–2.5	5
2.6–3.0	4
3.1–3.5	3
3.6–4.0	2
4.1–4.0	1
>4.5	0

Worker's Compensation Cost Claim Cost Incurred (dollars per employee)	Points
0	10
1–17	9
18–33	8
34–50	7
51–66	6
67–83	5
84–100	4
101–116	3
117–133	2
134–149	1
> 149	0

Compliance With Safety Standards

1. Two points are deduced for each *serious* deviation from standards that could result in one disabling injury or significant property damage or repeat violation from previous inspection.
2. The formulas below define the points deducted for each *non-serious* deviation from standards. There is a maximum of one point deducted for cumulative deviations from one standard.

Group (see Figure 37-2)	No. Employees	Point Formula
1	400 or more	1 for every 4 items of noncompliance
2	250–399	1 for every 4 items of noncompliance
3	125–399	1 for every 3 items of noncompliance
4	70–124	1 for every 3 items of noncompliance
5	< 70	1 for every 2 items of noncompliance

Risk Analysis

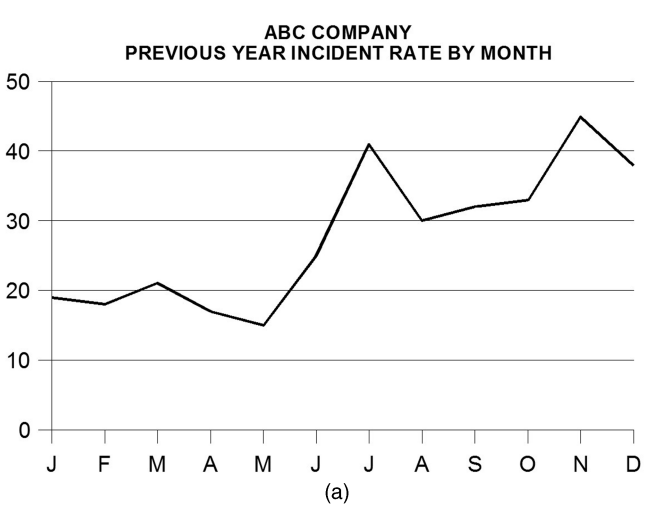
Based on 23 five-point rating scales on program and procedures. The score is based on the percent of the maximum points possible on the rating scales and that allowed on the rating form.

Line Management Support

Based on structured interviews with top management and line supervisors. Five-point rating scales are used to evaluate the responses to each interview question. Points are based on a percent of maximum points possible.

Safety Program

Based on a review of how safety programs are implemented. A series of questions have five-point rating scales. Points are determined as a percent of maximum points possible.



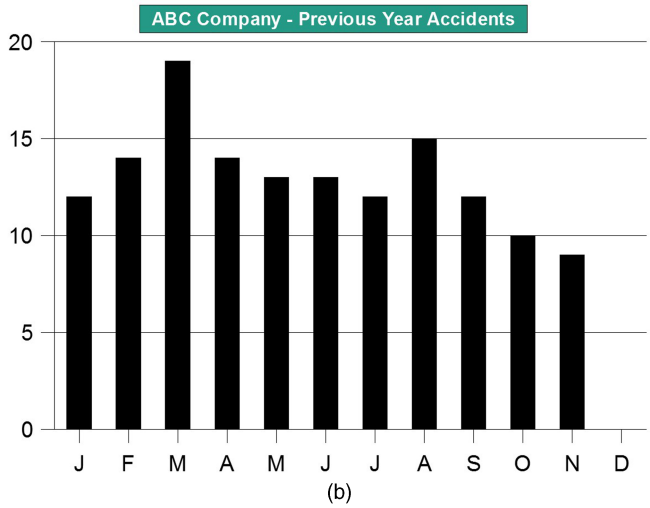


Figure 37-8. Examples of (a) line and (b) bar graphs.

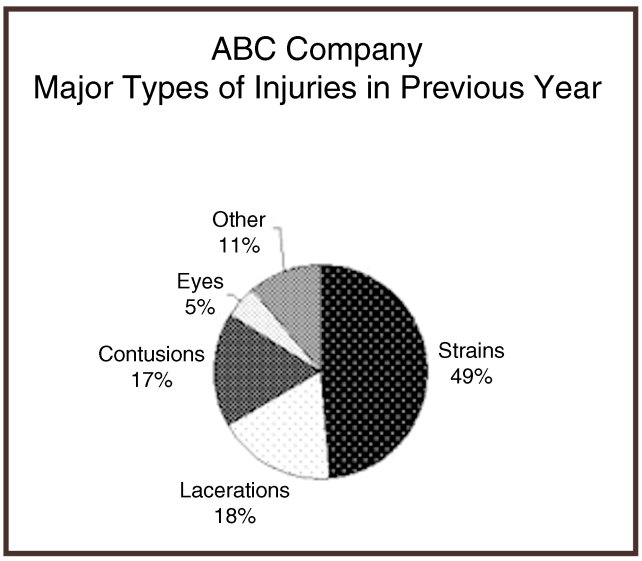


Figure 37-9. Example of a pie chart.

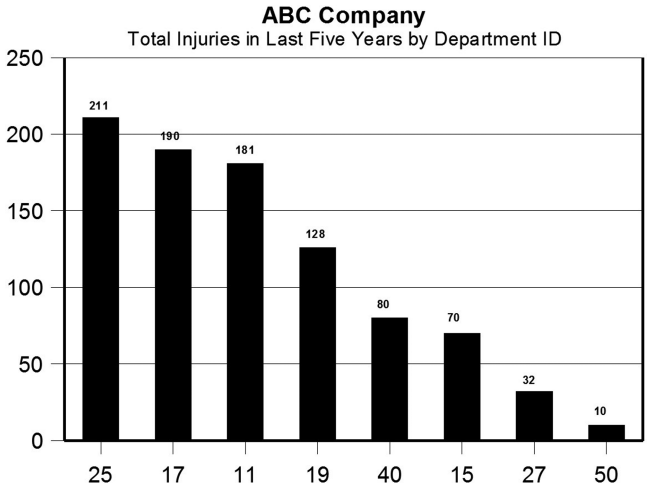


Figure 37-10. Example of a bar chart comparing injuries classified by numerical category codes.

Bar charts help to compare performance among organizational units. There are various types of bar charts. Stacked bar charts show the contribution of each unit to the whole for different periods or elements. Bar charts that show values in descending or ascending order help compare different groups. Figure 37-10 shows one type of bar chart for communicating safety information.

37-7 COMPUTER SYSTEMS, THE INTERNET AND SAFETY

Like many other professionals, safety specialists must use computer tools to record, manage, analyze, and communicate information. This section identifies some computer systems and software applications for safety and health. The discussion will not address many general and commercial products and applications. One can refer to trade publications or find products at safety and health conference exhibits. Computer specialists will have knowledge of general applications and computer tools.

This discussion mainly refers to capabilities for small business computers. With the rapid changes in computer technologies, it is difficult to cover all levels of devices and applications. For example, with the introduction of laptop computers, tablets, and smart phones, the variations in software and applications have also expanded rapidly.

The Internet provides a way to link many information devices and capabilities. The Internet also provides access to a wide range of data and information useful in performance

analysis. This book provides many notes about Internet resources. The Internet provides a way to manage transactions from anywhere using a wide range of devices. It supports nearly instant communications in a variety of forms. For example, social media can link workers, managers, and others with safety information and support. The Internet allows instrumentation and monitoring systems to send data directly to collection points for analysis and interpretation. Results can trigger alarms and produce danger notices immediately.

Security of data has become an important consideration. With the expanded use of the Internet, unauthorized individuals may gain access to private and confidential information found in safety software and applications. It is illegal to make some personal information available. Examples are human resource information, medical information, and other data that may link to accident and injury or illness cases. One kind of security involves keeping secure data and information on computers that do not link to other applications. Another kind of security involves encryption techniques for secure data and information. When data and applications reside in other locations, the communication interfaces must be secure along with the remote computer systems themselves.

Data Base Management Systems

One of the workhorses of software applications is the concept of data base management systems (DBMS). Data base management system applications provide ways to compile data in an orderly fashion and produce a range of reports that offer information about the data.

DBMS applications consist of data entry forms, data files, standardized reports, and custom queries of data. Data files are often simple tables. Across the header are columns devoted to different data elements. Each column may have a label to identify what data are in the column. Each row in the table is a different record or data set. For example, each row might be data collected in conjunction with an accident. Some people try to build basic data files using spreadsheets. The spreadsheets have features for structuring some analysis. As data files become more sophisticated, a DBMS application will be better. Reports can incorporate a wide range of analysis.

It is not difficult to develop DBMS applications. However, some applications become complex and require significant programming work. DBMS platforms contain features that eliminate many of the programming tasks. A basic example is Microsoft Access®. There are advanced platforms that work across operating systems and equipment. Some DBMS products also produce compiled code for an application. Compiled code runs faster. A developer can sell or give an application away separate from the platform. DBMS platform software requires a product license.

Most DBMS products allow data entry using on-screen forms, barcode readers or direct input from instruments or other devices. All DBMS systems offer ways to construct and produce output reports. Some offer custom reports using query-by-example or other easy-to-use techniques. A query allows a user to look up combinations of data element (table columns) and restrict which data records (data table rows) to include. Some allow transfer of reports to other software, such as business graphics or systems. Many DBMS products have security features that limit access to data by particular people.

One example of a DBMS application involves managing fire extinguishers. Suppose an organization has extinguishers placed throughout a large building or group of buildings. Someone must know what type each is, when it went into service, when it was tested last, and when someone completed a visual check on it. A DBMS application saves a lot of time in managing the extinguishers. Initially, someone lists each extinguisher in the database. The information may include brand, model number, serial number, supplier, capacity, extinguisher type, ID number, and similar data. Then someone completes an inspection periodically to assure that each extinguisher is charged and useable. There may be a tag on each extinguisher to log the inspection date. The inspector may have a hand-held device that reads barcodes. The device can read the ID number and allows for entry of date and time and conditions found. Someone who handles testing may pick up the extinguisher and take it to a location for testing. Data for that activity also gets logged. Someone can look up information and establish a work schedule for inspections, testing or other actions. Such a report may be a standard report in the DBMS.

Relational DBMS platforms solve some complexities of data collection and management. Relational data bases allow linking of separate but related lists or tables of data. The concept eliminates duplicate data.

An example may apply to extinguisher management. Each extinguisher of the same model may have important data about type, size, etc. Two linked tables could eliminate the need to enter all model details for each extinguisher. A table of models details requires entering details for each model only once. It is not necessary to have those data entered for each extinguisher. Having a model number in the table of extinguishers and also in the table of model details allows for a link. The DBMS application can pull information from both tables and display it. Or one might click on a model number on a screen to get a window with the model details.

A more complex example is that of safety training for employees. A person may attend more than one training session in a year. One list would contain the course and data about it (title, when given, duration, where given, and a course ID). Another table might maintain a list of attendees for each course and notes about their attendance or

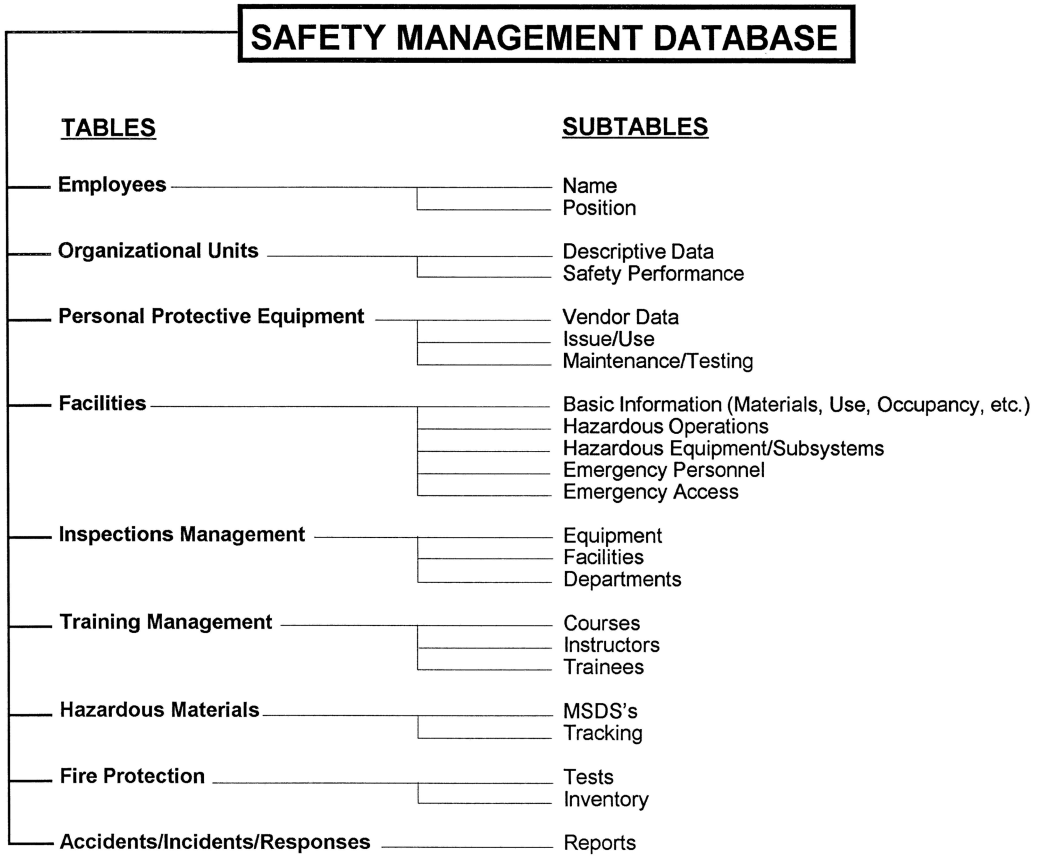


Figure 37-11. Example of a structure for a safety management data base.

performance on quizzes. A third list may contain data about the attendees themselves, such as name, department, age, address, phone number, email, etc. If there were only one list for managing training, there would be a lot of duplicate data. Having linked, multiple tables simplifies the data collection and retention. A relational database can manage the links, as long as there is one common data element to form a link. A person's name can create one link. The course ID can create another link. All three data tables can link together to provide training management reports containing data from each of the three tables.

Over the last decade or so there have been many commercial DBMS products for managing safety data. Some have survived the rapid rate of change in computer systems and the competition.

There has been a rapid growth in the data required for safety management. Today it is essential to keep track of many kinds of data. There is a need to capture incident and accident data. There is a need to track personal protective equipment issued to individuals. There is a need to link hazards and exposures to jobs and those in those positions. There is a need to track exposures of employees, training given or required for them, job assignments, and other factors. There is a need to track hazardous materials data. It may be important to keep track of fire extinguishers, hoses, hydrants, and other fire protection data. There is a need to track controls for hazards put in place. There is a need to track product ownership, recalls, repairs and modifications.

Figure 37-11 illustrates the structure of tables in a relational data base for an employer who must track many safety matters. Each table contains information about the items included in it, including employees, training, accidents and incidents, equipment issued, exposures and physical tests (hearing, pulmonary function, BLV tests, etc.).

Modeling

Another use for computers in safety is modeling. Most common is modeling of processes and the hazards the processes create. Modeling allows people to anticipate what might happen or understand what did happen. The accuracy produced by a model depends on the availability of accurate data, the inclusion of factors that can affect the phenomenon and adequate representation in the mathematical manipulations. There are reasonably successful models in safety for automobile accident reconstruction, for gas dispersion, and for fire behavior in small buildings. Some software allows users to construct a model of a unique

process to ensure that work flows without bottlenecks or other problems. Some models have become sophisticated. Some companies do not allow anyone to change a process in place without testing the impacts of change in a model of the process. The model may incorporate hazards and analysis of their impact on changes.

Vehicle accident reconstruction models allow analysis of what happened in the sequence of events before, during and after collision. The models depend on accurate information about particular automobiles and data from crash sites. Chapter 14 introduced accident reconstruction modeling.

Gas dispersion models can plot the formation and movement of gases released from point sources. The models help to plan emergency response strategies and procedures for accidental releases. They help consider impacts on surrounding facilities, people and communities. When dealing with an actual release in real time, models have limitations. They may not have accurate data on current wind or atmospheric conditions. Differences between a computer model and the actual event can be critical when trying to manage an emergency response.

The National Institute for Standards and Technology (NIST) developed models of fire behavior and exiting behavior of building occupants during a fire. That has resulted in several models, some of which are commercial products. NIST conducted a review of software for modeling fire egress.[13]

There are also successful models of fire and smoke behavior in buildings. These systems allow for analysis of the adequacy of building designs and what happened in certain building fires. NIST has reviewed several software models.[14]

Training Management Software

There are many requirements for training people about safety and health matters. A wide range of computer products for training development, training delivery, training evaluation and training management help meet these requirements. The products fit training delivery for various rapidly changing media. In general, computer tools for training delivery has the name *computer-based training* (CBT). One of the features of computer-based training is the ability to customize and vary the training for different situations, groups and individuals. One can adjust contents through easy-to-use training development software.

Some development software offers adjustments for individuals. Some individuals may have experience and knowledge that others do not. When a program delivers training, it can include incremental diagnostic elements to detect whether someone understands the contents fully or not. If they do not, the product can move to remedial or background components to build a foundation for content not fully grasped. A student can move through those components as often as needed to achieve the same knowledge that other students demonstrated during initial presentation. This variable feature removes peer pressure and fear of failure. It allows students to make mistakes during learning. The feature helps ensure that all students master the content of a presentation, regardless of background.

CBT systems support a wide range of delivery media, including personal computers, laptops, tablets, and smart phones. The products work in computer systems and Internet-based systems. Presentation software manages lesson presentations. Presentation software can also time and score student progress and record completion of each lesson to help manage training.

Authoring software for preparing CBT lessons helps design and prepare text and graphic materials. It fosters inclusion of evaluation questions and exercises. Some product support delivery of examinations. The evaluation items diagnose student mastery of and deficiencies in lesson objectives. Some students may take different routes to achieve the lesson objectives. Some may receive extra help when diagnostics indicate the need.

Tracking

In safety, there is a need to follow the movement of hazardous or other items from location to location. Computers can assist in that function.

There are several technologies that can help with tracking tasks. Use of these technologies helps in recognizing particular items and establishing their locations. Bar code devices, optical character readers, magnetic strips, radio frequency transmitters, global positioning systems (GPS), and other automated identification and tracking technologies are essential. One can place a bar code label on a container of a hazardous material. At each check point along its path of movement and use, someone reads the bar code and identifies the item precisely. Additional technologies may capture the location or organization receiving or transferring the item. The data gets captured into a central system. It is possible to display locations in a graphic representation or map. Reports from the data base can detect time or location deviations and signal an alert.

For example, tracking systems are vital to manifest procedures for hazardous materials. GPS system links attached to a truck and to shipped hazardous materials allow real time tracking for both the vehicle and its contents. It is possible to detect any difference in locations for the two. A difference indicates that something has affected the transport of the material.

Another example is tracking safety-related repair and maintenance activities. When a work request comes in, someone attaches an identifying bar code. The maintenance worker logs information into a management system about the item, problems, repair or maintenance needed, diagnostics, actions completed, and final resolution, such as approved for

return to use, forward to a supplier or disposal. At each step, someone scans the barcode to identify the exact item. Various system reports show status, down time, work completed, parts replaced or repaired, and final condition.

Systems can also track people. For example, some location may have access for only some people. Those entering a check point may need to scan an ID badge or mark their entry through other personal identification technologies. Alternate technologies may be fingerprint readers, retinal pattern readers, facial recognition, or voice recognition. The system can capture entry and exit and record times for each. Reports can show which individuals were present at the same time, total time in the restricted location and other information.

Monitoring

Another important use of computers in safety is monitoring. One can place sensors and data capturing devices to detect the occurrence of unsatisfactory conditions. Sensors feed data to a computer. The system analyzes the information to identify some dangerous condition. It can set off alarms and distribute urgent messages to people who need to know about a condition. There are monitoring systems for certain hazardous gases, for excessive heat or fire, and to detect system failures.

Data Banks

Data banks are another important tool for safety people. Most data banks use Internet access. In relying on Internet sources, one must take care to establish the reliability of information sources. Data banks can help people keep up with rapidly changing laws and regulations. They can be sources of knowledge and information for special safety problems. Professional, government, and private organizations may compile information useful to many others. There may be membership or on-demand fees for access and use. Some have bibliographic records, accident and incident records and other safety-related information. There are data banks on pesticides and their effects, chemical hazards, auto safety, radiation, earthquakes, lightning, tornadoes, and other topics. There are data banks on legal claims related to products liability and product recalls.

There are many examples. The National Highway Traffic Safety Administration (NHTSA) works with auto manufacturers to establish vehicle recalls for safety issues. A huge recall involving many manufacturers and vehicle brands and models dealt with an air bag issue. The model of the device that automatically inflates an air bag sometimes created shrapnel that could injure or kill a driver or passenger. Individuals could look up their vehicle by vehicle identification number (VIN) to determine if the list includes their vehicles in the recall. NHTSA offered the database on its web site.

Expert Systems

Expert systems help perform reasoning. A common kind of reasoning is diagnostics. A physician must apply reasoning with most patients. A physician gathers information from the patient and from tests. Based on the information, the physician makes a diagnosis of the illness and prescribes a remedy.

Expert systems may apply inductive or deductive reasoning. Inductive reasoning goes from the specific to the general. Most often it is the approach of a physician, i.e., getting specific information and generalizing from it. Deductive reasoning goes from the general (a theory) to the specific (an observation). The hypothesis must be true for deductive reasoning to be correct.

For a time there was a lot of interest in expert systems. The concept makes good sense. Development of an expert system was not always easy to accomplish. Some were not effective. Expert systems, both inductive and deductive, may prove to be useful computer tools. They help perform some reasoning.

Expert systems have several uses in safety. One type of application is diagnostics. A diagnostic system can help someone with little knowledge to work through an issue and reach a decision. Recall that Failure Mode and Effects Analysis is similar to a diagnostic chart. Someone enters characteristics of a product or process problem. The system offers advice on the problem and what to do about it. Some applications address selection and use of ladders and scaffolds. They can help with other decisions, particularly those involving decisions that require probability and severity input to decide on preventive actions. There are some applications in products liability that weigh information in a product injury lawsuit and against costs to decide about moving a case forward. Based on data from previous and similar cases, the system will advise whether to settle the case, move to a trial, or discontinue the case.

Computer Aided Design

Computer aided design (CAD) is another useful computer capability for safety. CAD systems mainly provide layout drawings for parts, assemblies, buildings, and sites. The more sophisticated CAD systems allow users to tie materials, equipment, and other items to the drawings. For example, a CAD drawing is a good way to chart hazardous areas on site maps or building floor plans. A layer in the drawings may present hazardous areas or other hazards important in planning construction, maintenance and repair of buildings and land.

Some CAD systems link with DBMS files. For example, a floor plan may show the locations of fire extinguishers, eye wash fountains, and other safety equipment in a building. Each fire extinguisher may be part of a DBMS fire extinguisher management system. When creating a work plan for

inspection and testing, the management system could create a drawing and highlight the exact fire extinguishers and their locations. The combined CAD and DBMS information could support analysis to assure that extinguishers meet capacity, spacing, and other location rules.

Process facility drawings may show level of hazard or other characteristics through color or shading. CAD drawings may have special symbols or components of interest to safety. For example, compressed air lines and terminals with 30 lb/in.^{2} or less may have a particular designation. Drawings of pressure lines may specifically identify pressure relief devices and data about them. Linking safety DBMS systems to CAD drawings, drawing symbols, and drawing layers can help with safety management tasks.

The interface of CAD information with DBMS continues to improve. This provides the capability to extend management of safety information further. For example, there may be a need to associate accident data by department with floor plans. Drawings can show the exact location for each accident. The drawings can add insight into frequency and severity of accidents. In a similar way colors or shading can represent risk types or severity levels on floor plans or site maps. The risks may show the kinds of hazards.

Special Computer Applications

There are many special computers or computer applications in safety. Some companies have programs and special devices for assessing hearing loss and logging test results into data bases. There are special computers for evaluating pulmonary functions. There are software tools for evaluating lifting tasks. There are special sensors and computers (some very small and worn on a person) to monitor noise exposure and compute noise dose. Some monitor exposures to hazardous chemicals. There are computer applications for analyzing laser hazards. There are programs for designing ventilation systems and sprinkler systems. There are programs to help deal with risk analysis, for monitoring environmental conditions, potential gas leaks, and other hazards.

Communications and Social Media

This is often a need to communicate with people about dangers that emerge. For example, weather conditions may require people to change normal behavior and minimize dangers. A golf course may have a alarm sound that gets golfers off the course when there is lightning. Winter storms that produce blinding snow and icy road conditions may require early dismissal of employees. A security threat at a facility may require implementing a lock down or other protective procedures. When such conditions arise, people need notices.

Most facilities have fire alarms to signal occupants to exit. Some communities have tornado sirens that provide warnings. Beside built-in fire alarms, there are computer, speaker, and smart phone systems that can broadcast alerts. An organization must identify the potential threats and dangerous situations, have emergency response policies in place, and trigger communication systems. There are automated telephone calling computer programs that can send phone calls and messages to everyone included in the call list. Social media also offer ways to distribute emergency information quickly. Depending on a single communication method is not always possible, since not everyone who needs the emergency information may have the capabilities to connect to the system. They may not have their receiving devices turned on even if they have connections. Multiple communication methods may be necessary.

Each kind of emergency communication plan must include a list of people who need information or instructions. The plan must include the message or examples of messages, the decision method, the list of people who need the message, and the systems used to implement the communications. Records should include when and how an emergency communication was handled and executed.

EXERCISES

1. A company has the following accident frequency by month over a two-year period:

Year	J	F	M	A	M	J	J	A	S	O	N	D
lst	19	12	32	24	27	18	26	30	16	20	28	32
2nd	16	36	17	23	29	21	30	18	25	28	13	33

Prepare a control chart for these data and plot the actual data. Calculate and show the upper and lower control limits with the mean frequency. Determine if the frequency for any month extends beyond the control limits.

2. A team was sent to a number of departments to monitor worker behavior. The goal was to determine how safe worker activities were. The team found that 82% of the behavior was safe. The team sampled each department during 20 observation periods. Frequency data suggests that performance could be better. A new safety program will be implemented to improve the performance.

(a) If there are 18 departments and a 95% confidence level is applied, what are the upper and lower control limits for evaluating the behavior in particular departments?

(b) If the follow-up study is to have an accuracy of 10%, how many observations must be made in each department to achieve this accuracy at a 95% confidence level?

3. Obtain a copy of a report of the NTSB accident investigation of an airplane accident. Find out what procedures were followed, how many investigators participated, and what the findings were.
4. Identify Internet resources for:
   (a) regulations and standards
   (b) state and federal laws
   (c) safety equipment and personal protective equipment
   (d) training materials and services
   (e) record-keeping systems
   (f) professional development conferences
   (g) accredited safety and health certifications
   (h) safety and related academic programs

REVIEW QUESTIONS

1. What are three purposes for analysis?
2. Where do accidents fit in accident prevention strategies?
3. What types of inspections are there? Give an example of each applied to safety.
4. Who is qualified to be an inspector?
5. Identify tools used in inspections.
6. What is a safety audit? What is the main purpose of an audit?
7. Where do accident investigations fit in the process of preventing accidents?
8. Why are accident investigations important?
9. What kinds of accident investigations are there? Give an example of each type.
10. Should all accidents be investigated? If not, why?
11. What strategies can be used to select particular accidents?
12. Identify tools used in accident investigations.
13. Describe an accident investigation process.
14. What methods help evaluate the safety performance of an organization?
15. What is a control chart? What is its main purpose? What are its limitations?
16. What are some subjective methods for assessing safety performance?
17. Identify four kinds of business graphs that may be useful in presenting results of analysis. When is each more useful than the others? Give an example of each kind of graph.
18. Explain data base management systems.
19. Explain relational data base management systems.
20. What is computer modeling? How can modeling be used for safety?
21. How can training software help manage safety training?
22. What is CBT?
23. What are tracking systems? How are they useful for safety?
24. How can monitoring systems help in safety management?
25. Give examples of safety-related data banks.
26. What is an expert system? Explain the types of logic expert systems use.
27. What is CAD? How can CAD systems help in managing safety issues?
28. What systems can help communicate emergency information to employees, customers, and communities?

NOTES

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3 ISO 14000 *Environmental Management*. www.iso.org/iso/home/standards/management-standards/iso14000.htm

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5 ISO 45001 *Occupational Health and Safety Management Systems - Specifications*. www.iso.org/iso/news.htm?refid=Ref1874

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CHAPTER 38

SAFETY PLANS AND PROGRAMS

38-1 INTRODUCTION

The previous chapters in this section discussed a variety of approaches for managing safety and health. Recall that the goal is to eliminate or reduce accidents. Engineers may perform many kinds of analyses to identify hazards and pinpoint controls that will reduce accidents. Managers also have a role in eliminating and reducing accidents and incidents. Recall the hierarchy of controls (Chapter 9) includes procedures as the last step. Managers have a major role in this step. They want to know what to do and the actions to take. They need to provide the leadership for an organization or work group. They want to know what the actions will achieve, what the actions will cost, what human resources are necessary to accomplish the actions and the schedule for completion of the actions.

A good way to organize and implement safety procedures is through plans and programs. A safety and health program is a written plan of action to prevent injuries and illness. Plans and programs start with policies and move to procedures as discussed in Chapter 35. A program may result from a plan for dealing with hazard recognition, evaluation and control strategies. The program may be a separate document that states how an organization will operate given an understanding of the problems addressed. There may be a general safety and health program that applies across a company or organization. There are also specific programs targeted at particular kinds of hazards or processes.

Plans and programs involve employees and employers. Each has responsibilities in achieving safe and health workplaces, products, and services. Government agencies sometimes mandate written programs.

A plan may begin with hazard identification and analysis methods or it may be the consequence of such methods that offers recommendations for improvement. A plan includes at least three components: (1) a list of actions or tasks and who will complete them; (2) a schedule for their implementation; and (3) an estimate of costs. Costs may include human resources, as well as monetary resources. Specific plans may have additional components. Once approved, a plan is set into motion. The implementing document may be a program document.

Plans and programs are much the same. Plans are documented strategies for getting things accomplished. They may or may not get implemented. The term program infers something larger than a plan. Programs address goals of an organization. Programs will establish implementing policy and will detail the procedures an organization will follow. Programs may include specific operating procedures.

This chapter looks at examples of plans and programs for achieving safety and health. References offer additional details and help when dealing with specific laws and regulations. There are also consulting companies that provide services to develop written safety and health program documents.

38-2 PRODUCT SAFETY PROGRAM

Many factors contribute to the safety of a product. A manufacturer does not have control over all the factors. However, an important manufacturer's goal is to minimize the contributions product design, production, advertising, distribution, and warranty have on accidents and injuries for buyers or users.

Depending on products, government agencies offer details and guidance for products. For consumer products there are guidelines for the United States,[1] Canada,[2] Europe,[3] and Australia[4] as examples. The Consumer Products Safety Commission offers guidelines to support product safety programs.[5] An effective product safety program will address all aspects of a business that impact a product and its sales, support, and use.

Executive Action

Executive actions are those that require support from top management to make them work effectively. Executive

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actions provide the commitment for success, not just support in principle.

Policy The first evidence of top-level commitment is a written policy statement. It should state the objective for product safety and cite statutory, voluntary and company standards to follow. The policy should also have a commitment to maintaining state-of-the-art safety features in products. The policy should assign responsibilities to particular elements of the organization. The organizational units may include internal line and staff organizations as well as suppliers and distributors. It should state how effective relationships help achieve safety for buyers, users, and consumers of products. The policy should identify the methods the company will use to judge product safety.

Organization and Staffing Internal procedures need to identify what each element of an organization must do to achieve product safety. A product safety program assigns responsibilities, authorities, and actions. Each organizational unit will have particular procedures for its role in product safety. That includes procurement procedures and acceptance methods for components and parts. Procedures will cover design, manufacturing, quality control, distribution, sales, and customer complaints. Procedures will address methods for assessing performance and getting assistance with product safety program elements. Program details will identify how each organizational unit will participate in the product safety program.

Part of the program covers budgets, communication (brochures, technical manuals, etc.), record keeping, and analysis. Financial aspects will establish how insurance will cover potential claims and losses.

Training An important element of a product safety program is training. Participants in the product safety program must know their responsibilities and roles and how to perform them properly and effectively. Participants need to know their contributions, no matter how large or small, will help achieve success for the program and the products. Some participants will need formal training because of the importance of their roles. Others may receive training through other media.

Technical Requirements

Technical requirements refer to detailed procedures for the life cycle of a product. The procedures extend from planning and design through production, distribution, and final use by a consumer or user.

Design Review Design review involves the examination of the product itself, its materials and design, and its packaging and labels. The most important part of the review is hazard identification. The hazards may be inherent in the design or materials. They may result from use, foreseeable misuse, and the use environments of a product. Comparisons to similar products can help identify hazards. Tests must assure compliance with existing standards. Additional tests may extend beyond published standards. It is a good idea to retain test data for evaluation and future reference. If procedures identify hazards, there is a need to evaluate them for severity of resulting dangers. For each hazard, someone should define actions needed to eliminate hazards or reduce them to an acceptable level. Risk analysis may set priorities for eliminating or reducing the hazards and applying warnings and labels to the product. Procedures should cover how to resolve conflicting recommendations among reviewers.

Documentation and Change Control There should be a method in place to document design changes and the reasons for the changes. The process should pay particular attention to changes intended to reduce hazards. There should be a risk and hazard analysis for each change. Documents should note any changes in user manuals, service bulletins, sales brochures, advertising, and maintenance manuals. Documents should identify any remaining hazards and actions users must take to protect themselves from remaining dangers. Manuals need updates when products change to avoid misleading information that may lead to improper use.

Purchase Control One cannot depend on materials, parts, or assemblies being free of hazards. There should be procedures in place to ensure that purchased items, assemblies, or packaging have undergone risk and hazard reviews. Purchase decisions and purchase procedures should include steps to prevent hazards in parts or assemblies. There should be clearly defined actions when suppliers do not comply with purchase requirements, specifications, tests, or test certification.

Production There are many production practices that may affect product safety. One aspect is control of materials and assemblies. Handling and shipping may introduce defects. Thus, there is a need for checks, inspections, and tests. If there are inadequate parts, they must be clearly marked and pulled from production to prevent their use. There should be procedures for managing materials with limited shelf life so they do not contribute to product hazards.

There should be clear work and assembly instructions. Analysis of production steps will help ensure that procedures do not introduce hazards. Workers should have written instructions and standard operating procedures. The instructions should cover how to handle repair or disposal of defective products during production. Workers should have training in procedures to achieve safe products.

Product hazards may result from poor work environments and poorly operating equipment. There should be

analysis to detect when product hazards result from production equipment not working properly or being out of adjustment. Work environments should have adequate light and other conditions that ensure worker performance and product quality.

There should be a comprehensive review of the production process for impacts on product safety. The review may include periodic inspections, verification of worker qualifications, and other considerations.

Quality Control There should be ongoing quality control procedures. Quality control should address procedures in place and checks to assure that parts, assemblies, and the final product meet specifications and standards. Procedures may include a range of tests, inspection, and analysis. Should quality control uncover defective processes or products, there should be analysis to discover the source of deficiencies.

Measurement and Calibration Many inspections and testing methods depend on quality instruments. It is essential to inspect and calibrate instruments at regular intervals.

Distribution Design of packaging and selection of packaging materials can prevent the introduction of hazards during shipping and handling. There should be tests for packaging. Test procedures may also capture samples from field locations to ensure that packaging withstands shipping and delivery.

Consumer Service Consumers may need help with assembly, installation, service, repair, parts, and other matters to keep their products safe. Manufacturers can use product registration to help notify users of recalls and safety notices.

Customer Feedback and Product Records A variety of records can help achieve product safety. The records help identify the extent of problems across batches and production dates. Records help when contacting product users. Internal records may include results of tests, inspections, and checks by batch, lot, or serial number. Consumer complaints and reports of problems help identify safety problems. Consumer problem reports can come from phone calls, emails, or correspondence. Consumer problems may also come from sales and service staff. Records may link product lots, batches, or serial numbers with the distribution system. Records of current ownership is also important for some products that get resold among users.

Corrective Action Some product manufacturers must notify the federal government of hazards and defects that may affect users. It is also important to track hazards in products and the actions taken to eliminate or reduce them. It is also important to establish that products are in compliance with legal requirements.

Audits Product safety programs work well when there are planned and scheduled reviews of for all aspects. There should be periodic audits to assure that participants meet all program details.

38-3 OCCUPATIONAL SAFETY AND HEALTH PROGRAMS

Many elements of an occupational safety and health program contribute to its success. The essential elements will vary for each organization. Some elements apply to all organizations. Laws require some elements. Other elements vary with the structure and operations of an organization.

The emphasis on particular elements will change from time to time in response to changing needs of an organization. The summary that follows identifies many important elements. Individuals may add or delete elements. Some seek to give emphasis to particular elements. Some elements overlap with others, since elements are not completely independent.

Commitment

Strong support from top management is essential for the success of any endeavor of an organization. The same is true for an effective safety and health program. A safety and health program must include a clear statement about importance of safety for the organization. Top management must show strong support for safety and how an organization manages its safety and health program.

Policy and Procedures

An occupational safety and health program begins with a policy placing paramount importance on workplace safety and health and protection of employees. Some companies will extend its commitment to off-the-job safety as well. The message establishes the importance of workers arriving for work safely and returning home safely each day. Some employees may extend their commitment to the safety of employee families.

Extending the program beyond the immediate boundaries of employment has several effects. First, it assures employees they are valuable individuals. Second, it gets employees involved in safety throughout their lives. They do not turn safety on when they get to work and turn it off when they leave.

Procedures extend the policy into practice. The procedures assign responsibilities to each unit of the organization.

Occupational safety and health programs must involve everyone at every level in an organization.

Procedures explain what to expect and how to meet those goals. Procedures provide specifics for a range of activities. They include general safety rules that are part of work rules. Procedures may include a compilation of details and forms for particular operations and use of equipment and materials. For example, they address accident reporting, hot work and hot work permits, confined entry practices and permits. They cover methods and forms for dealing with hazardous materials. The detailed procedures may cover emergency responses for fire, weather, spills, leaks or other conditions. They will address how to work with workers' compensation. Procedures tell how to deal with a variety of hazardous operations and how to use certain equipment and materials safely. Procedures spell out participation in and operation of safety committees, fire brigades, and other special assignments.

Assigning Responsibility

A safety and health program must clearly identify who is responsible for what. Assignment of responsibility is normally a part of policy and procedures. Assigning responsibility must include the role for line elements of the organization, staff elements and special committees or other special units.

For example, supervisors in line elements are normally responsible for their work areas and the people under them. They may have to manage training, inspections and reporting of problems that create hazards. Supervisors typically must sign for dangerous operations that will occur in their areas. They may have safety included in their job description and job performance goals. Safety performance in their work group may be an element of their performance assessment.

Staff elements may handle record keeping, company-level reports, and other safety-related information management functions.

Safety and health staff will obtain special expertise, especially if it is not available within the organization. Safety and health staff will ensure that essential safety resources are available to work groups. This may include medical services, emergency services and equipment, training materials, and qualified instructors. Other resources may be safety engineering, ergonomics, fire protection, rehabilitation, first aid, occupational health nurses and physicians, and similar specialists. The safety and health staff will coordinate the purchase of personal protective equipment. They may review designs of facilities, processes, special activities and work areas. They will provide measurement and assessment of environments for hazardous conditions and materials. They will develop and manage the budget for occupational safety and health matters. They will perform major inspections, head inspection teams or organize inspection teams. They will assist line elements in all areas of safety and health implementation. They may develop special publications and communications with employees. The safety staff will develop and recommend safety and health policies and procedures for the organization.

Many organizations emphasize creation of a safety culture in which employees at all levels participate in safety. Increased training, validation of knowledge through testing and recognition of individual and group contribution to safety performance help achieve the culture. Effective safety leadership by managers and supervisors is essential.

Implementation

Implementation involves setting schedules and tracking activities. For some occupational safety activities, there should be fixed schedules. For example, some equipment or processes require daily inspections and records made of inspection results. There should be a regular schedule for activities of safety committees and other special units, such as a fire brigade. There may be weekly or monthly safety meetings of each organizational unit. The goal is to learn about hazards in work group operations, to identify safety problems, to review safety performance and recommend controls and improvements. In each work group implementation involves having someone ensure the group carries out all the activities of the occupational safety and health program. There should be records of the activities and reports of safety performance measurements.

Implementation includes compiling information using forms and procedures. For example, there will be accident and incident records and reports. There will be tracking of hazardous materials. There will be methods for making information available on hazardous materials for all organizational units that need the data. There is a need to compile information on safety-driven maintenance and repair of equipment and systems.

Implementation includes issuing personal protective equipment. It includes testing and inspection of personal protective and other safety equipment.

Implementation includes evaluation of work areas for environmental hazards. It may involve collecting and evaluating data from personal monitoring devices. It may cover testing and calibration of instrumentation and monitoring systems.

During implementation, there is a need to check fire protection and extinguishing systems and equipment. Some components require regular testing, maintenance, and inspections. For example, hydrants require testing for water pressure and flow. Extinguishers, alarm systems, and sensors require inspection and testing.

Implementation includes establishing and completing a regular schedule for training on emergency procedures. The training may range from fire alarm and evacuation drills to

training on use of fire extinguishing equipment. Training may include drills to test plant and community-level emergency response plans.

Training

There are many kinds of training associated with an occupational safety and health program. Chapter 32 discussed many aspects of training and training management. Workers must learn about the hazards related to their jobs and the means for protecting themselves. They need to know how to perform particular safety procedures. Users of personal protective equipment must learn how to use the equipment issued to them. Special safety and health units must learn how to perform functions associated with inspections, responses to emergencies and other activities assigned to their units. Also, someone must track the training required and completed.

Hazard Recognition and Control

Major elements of an occupational safety and health program address recognition, evaluation, and control of hazards. The activities may include risk assessment and charting of probability and severity of potential incidents. The activities may deal with routine functions as well as non-routine functions. Changes in operations and conditions or equipment may also trigger these activities. Inspections, reviews, and other analysis methods will help identify the hazards, the likelihood of occurrence and the potential severity. For example, there should be inspections of repair and maintenance work to ensure that guards and other protections are in place or an area is clear of flammable and combustible materials and sources of heat and fire. Previous chapters offered several methods for hazard recognition and control.

Hazard identification should be a procedure for new or modified operations, equipment or facilities. Someone must recognize any hazards introduced. Then procedures must evaluate hazards for severity and likelihood of accident occurrence. Procedures must identify suitable controls along with their potential effectiveness and cost.

Hazard recognition and control may include implementation of reviews of standard operating procedures. One or more people may review periodically operating procedures of each organizational unit or process. The review will identify hazards and risk and recommend controls for them if the controls are not already in place.

Budget and Cost

A safety and health program must develop an operating budget to complete the elements of the program. The budget may cover program elements of individual organizational units or focus on total safety and health program activities. There should be a way to track the costs of safety activities and purchases. Projecting cost and tracking actual expenses allow safety and health program leaders to measure financial performance.

Program Performance

Assessing program performance is an important element of a safety and health program. This requires tracking accidents, injuries, and illness. It includes tracking of activities tied to other leading and trailing indicators. It requires keeping track of completion of planned and unplanned safety and health activities. Assessment may be both quantitative and qualitative. For example, an organizational element may complete required safety meetings and training but as a result show no reduction of loss rates or risks.

Performance should include assessment of program objectives and results by organizational unit, by program element, and for the entire program. Previous chapters discussed methods for assessing safety and health performance.

There needs to be feedback and recognition of performance by individuals, organizational units, and program elements. Many organizations have safety and health performance awards. Some awards may link to competition among groups. Some may recognize accomplishment of safety and health program goals. For example, a company may recognize individuals who achieve a safe driving record or a safe job record. There may be recognition for developing special skills in first aid or fire response tasks. There may be awards for completing training courses or course sequences. There may be recognition for service on safety committees or involvement outside the organization in community safety activities. Organizational units may compete for risk reduction or hazard reduction achievements.

Audits are another part of safety and health program assessment. Audits should help determine the overall effectiveness of the safety and health program. Audits should verify compliance with safety standards, company policies and procedures, and safety plans.

One means for recognizing effective employer safety and health programs is the Voluntary Protection Program (VPP)[6] program of OSHA. The VPP seeks to get employers to partner with OSHA to create safer and healthier workplaces for employees. The program emphasizes developing effective safety and health management systems through incremental steps to improve safety performance. The program design allows individual employers, corporations and construction companies to participate. When they meet certain guidelines and achieve certain safety performance standards, participating companies move progressively from a “challenge” level to a “Merit” or “Star” level. Based on reporting and performance, OSHA recognizes the companies achieving each level. Overall, the VPP program has reduced

days away from work to 53% of the average for a typical industry group.

OSHA and Other Requirements

The Occupational Safety and Health Administration regulations call for written programs for specific hazards and procedures. Employers dealing with any of these will need written program documents. OSHA inspectors may want to review the programs and documents during an inspection. Employers must avoid simply adopting a sample program from an Internet site or a commercial provider. Programs must fit the operations and processes of an organization, they cannot be generic.

Examples of OSHA-required plans include those listed below. There are also other OSHA program requirements. The listings include OSHA guidance publications and other information sources.

- Bloodborne Pathogens (OSHA Publication 3186. OSN, 2003[7])
- Fall Protection
  - Sample Fall Protection Plan for Residential Construction[8]
  - Sample Fall Protection Plan - Non-Mandatory Guidelines[9]
- General Safety and Health Programs
  - Sample Safety and Health Program for Small Business[10]
- Hazard Communication Standard (OSHA Publication 3695, 2014[11])
- Lockout/Tagout
  - Typical Minimal Lockout Procedures[12]
- Powered Industrial Trucks
  - Sample Powered Industrial Truck Operator Training Program Outline[13]
- Respiratory Protection (OSHA Publication 3384-09, 2011[14])

There are requirements in Canada[15] and other countries for written workplace safety and health programs.

38-4 ERGONOMICS PROGRAM

When an organization or company feels that it has or potentially has ergonomic-related losses, it is useful to establish an ergonomics program as part of an overall safety and health program. The major elements of an ergonomics program include:

1. Verify the problem and its scope or potential scope.
2. Gain the support of top management.
3. Develop implementing procedures and organization.
4. Train participants.
5. Track program progress and evaluate its effectiveness.

Verify Ergonomics Problems

In this element someone evaluates various sources of information to determine whether ergonomics problems exist in an organization and are of sufficient frequency or severity to warrant further action. For example, one may review accident records or conduct an ergonomic analysis of certain jobs. The results may show there is a significant problem. For some organizations the driving force behind the analysis is fear of a general duty citation and fine from an OSHA inspection. See Case 33-2. An organization that completes its own evaluation and establishes an ergonomics program could reduce the ergonomics problems, associated costs and potential fines.

Top Management Support

Like other programs, support begins with top management for an ergonomics program. Company leadership must agree that program actions are necessary and valuable and deserve budgetary support.

With management support, developing an ergonomics program leads to additional details, such as policies, procedures, and a plan of action.

Prepare for Implementation

The ergonomics program should gain the participation of many elements of an organization. One goal is to recognize particular ergonomics problems and develop ways to eliminate or reduce them. Some organizations establish an ergonomics committee to help coordinate program implementation. A committee usually includes expertise in ergonomics matters, managers, staff specialists such as engineering, workers, and union representatives. The group may have to develop policy and procedures and may need to get special assistance with particular problems.

One type of procedure involves evaluation. The group needs to establish how to decide which ergonomics problems to tackle first. Also, it will need to find ways to measure the effectiveness of program actions. Several approaches may help. Examples are reduced claims, reduced ergonomics-related accidents, and degree of participation.

One major task of the ergonomics committee is identifying existing and potential ergonomics problems. It is easy to identify those problems that have already produced accidents, disabilities or worker compensation claims. Additional

analysis of job tasks, workstation designs, equipment designs, and worker complaints will identify additional ergonomics problems to consider.

Another task of the ergonomics committee is determining the procedures for implementing corrections and improvements. The procedures may consider cost to implement, potential reduction in injuries and claims and other factors. The cases that offer the best return on investment will usually get the highest priority for implementation.

Train Participants

Another task for the committee is developing and implementing ergonomics training that will help the program succeed. One aspect of training is awareness of causes and contributing factors for repeated motion injuries, lifting injuries, computer workstation disorders, and other ergonomics problems. Training should cover proper adjustment of chairs, tables, and other equipment. It should cover proper lifting and bending and use of adjustable pallets, and parts bins. Training should address company policies on ergonomics and its commitment to preventing and correcting ergonomic problems.

Track Progress and Effectiveness

This part of the ergonomics program manages, monitors, and measures the program. Program leaders keep track of identified ergonomics problems and their prioritization, actions initiated to eliminate or reduce them and the effectiveness of the solutions. They follow accident reports and workers' compensation claims for ergonomics matters. They track budgets and costs.

38-5 EMERGENCY RESPONSE PLAN

Many know Title 3 of the Superfund Amendments and Reauthorization Act of 1986 as the Emergency Planning and Community Right-to-Know Act of 1986. Some call this SARA Title 3. The law requires companies that store, use, emit, or move hazardous substances in a community to make details about those substances available to local authorities. Local governmental units, often working closely with such companies, develop plans to respond appropriately should a spill or leak of material occur within the community. This is a form of safety and health program.

This section summarizes components of an emergency response plan. One planning guide comes from the National Response Team,[16] an interagency group at the federal level. Many state governments also publish guides for developing and implementing emergency response plans.

The Process

Step 1. Type of Plan The process of developing an emergency plan involves at least five steps. The first step is defining the type of plan. This step assumes that a government body should develop a community emergency response plan. Given the need for a plan, there is also a decision about how detailed a plan should be. A plan may extend from a simple procedure about who to call and when to begin a list of activities for specific kinds of emergencies to a detailed plan involving responsibilities for many different organizations and companies.

Step 2. Organizing the Participants The number of participants in an emergency response plan typically increases with the amount of detail covered by the plan. It is important to involve all potential participants in the planning process. They may have information and insight that contribute to a comprehensive and effective plan. Participants may involve fire and police departments, medical organizations and hospitals, companies transporting or using hazardous materials, emergency organizations, and local and state government bodies. There may be companies or organizations with special equipment and materials. There may be companies that specialize in cleanup and disposal services. Participants may involve consultants or specialists in certain fields and members of the media.

Step 3. Conducting a Hazard Analysis The actual plan begins by defining the problems that may require emergency responses. The problem definitions result from a hazard analysis and identifying hazardous materials that could affect the community. There are many sources for information about hazardous materials. Included are local companies, users of materials, transportation organizations and companies, and waste handlers and disposers. For each hazardous material, analysts must determine the hazards and quantities present or potentially present in the community. The planning team must know the potential distribution media (air, water, soil, vehicles, rail, etc.) and how each potentially impacts community's residents.

Analysis should develop maps that show hazardous materials sources and impact areas. For shipped materials, planners need to know the form of transportation and the type of containers involved. Maps should show transportation corridors and zones of release to identify the locations potentially impacted by leaks and spills.

Analysts need to develop lists of organizations, data banks, and companies that are potential resources for responding to each type of material. The resources may range from technical advice to special response equipment and personnel.

Step 4. Writing the Plan The plan should include procedures and assign responsibilities for responding to each type

TABLE 38-1 Typical Contents of an Emergency Response Plan

Item	Explanation
Emergency Response Notification	List of who must be called and what information should be given when there is an emergency
Record of Changes	This is a table of changes and dates for them
Table of Contents	
Introduction	This may include abbreviations, purpose and objective, scope and applicability, policies and assumptions for the plan
Emergency Response Operations	This section details what actions must take place Typically they include 1. Notification of spill 2. Required federal notification 3. Initiation of action 4. Coordination of decision-making 5. Containment and countermeasures 6. Cleanup and disposal 7. Restoration 8. Recovery of damages 9. Followup 10. Special response operations 11. Agent-specific considerations
Emergency Assistance Telephone Roster	An up-to-date list of people and organizations who may be needed in an emergency
Legal Authority and Responsibility	This is a table of references to laws and regulations that provide the authority for the plan
Response Organization Structure and Responsibilities	This section describes the emergency response groups, their responsibilities and how they will work together
Disaster Assistance and Coordination	This section details where additional assistance may be obtained when the regular response organizations are overburdened
Procedures for Changing or Updating the Plan	This section details who makes changes and how they are made and implemented
Plan Distribution	This is a list of organizations and individuals who have been given a copy of the plan
Spill Cleanup Techniques	This contains detailed information about how response groups should handle cleanups. The methods may be specific for particular materials and kinds of spills
Cleanup/Disposal Resources	This is a list of what is available, where it is obtained and how much is available. The list may include contractors, materials, equipment, protective equipment, qualified personnel, disposal sites, etc.
Laboratory and Consultant Resources	This is a list of special facilities and personnel who may be valuable in a response
Technical Library and References	This is a list of libraries and other information sources that may be valuable for those preparing, updating or implementing the plan
Hazards Analysis	This section details the kinds of emergencies that may be encountered, where they are likely to occur, what areas of the community may be affected and the probability of occurrence
Documentation of Spill Events	These are various incident and investigative reports on spills that have occurred
Hazardous Material Information	This is a listing of hazardous materials, their properties, response data and related information
Training Exercises	This section identifies detailed exercises for testing the adequacy of the plan, training personnel and introducing change

of emergency. Table 38-1 is a sample table of contents for an emergency response plan. Completing the plan is difficult. Writers should refer to sample plans or plans written by other organizations. Plans already in place at nearby communities will help.

Step 5. Preparing for Use and Maintaining a Plan A plan needs testing through training and evaluation of incidents. There should be periodic drills to simulate incidents and engage participating organizations in executing a plan.

An emergency response plan is not static, but changes. There should be a periodic review process to ensure that data and procedures are up to date. Even simple things need checking periodically. For example, someone should call telephone numbers on call lists to ensure that they are still

correct. The responsible organization should regularly review and update its plans.

38-6 CONSTRUCTION ACCIDENT PREVENTION PLAN

The U.S. Army Corps of Engineers requires contractors who perform construction work for the federal government to prepare a safety and occupational health plan (SOH).[17] The idea is to analyze the potential work on a specific job or project and to plan accident prevention measures for each phase and component of the work. The plan includes work performed by subcontractors. It includes contractor hazard control measures. The plan must include frequent and regularly scheduled safety inspections of work sites, materials and equipment by competent persons.

The regulation requires preparation of an activity hazard analysis (AHA) before beginning each phase of work. This analysis addresses the hazards for each activity performed in the upcoming phase. It presents procedures and safeguards necessary to eliminate the hazards or reduce the risks to acceptable levels.

The publication identifies numerous program documents required for hazards that may occur on a job or project. The publication is more than 900 pages long. It is difficult to summarize here the many details covered.

EXERCISES

1. Visit a local company, governmental body, or emergency organization. Find out what emergency plans are in place and analyze them for completeness. Determine if they are up to date.
2. Review the safety and health program for a company. Find out what policies and procedures exist. Find out how a company maintains and evaluates its program. Find out what management methods the company uses to implement it. Identify the methods used to measure program performance.
3. Obtain a copy of the Corps of Engineers publication EM 385-1-1. Assume you are the safety officer for a contractor that will begin work on a construction project. Identify how you would prepare your employer for safety management of the project.

REVIEW QUESTIONS

1. What is the main goal for safety and health plans and programs?
2. List major elements for the following:
   (a) product safety program
   (b) occupational safety and health program
   (c) ergonomics program
   (d) emergency response plan
   (e) construction safety and occupational health plan

NOTES

1 www.cpsc.gov/en/Business–Manufacturing/Business-Education/

2 www.hc-sc.gc.ca/cps-spc/index-eng.php

3 europa.eu/legislation_summaries/consumers/consumer_information/l21253_en.htm

4 www.productsafety.gov.au/content/index.phtml/tag/mandatorystandards

5 *Handbook for Manufacturing Safer Consumer Products*, Consumer Product Safety Commission, 2006. www.cpsc.gov//PageFiles/113818/handbookenglishaug05.pdf

6 www.osha.gov/dcsp/vpp/

7 www.osha.gov/Publications/osha3186.pdf

8 www.osha.gov/doc/residential_fall_protection/sample_fall_protection.html

9 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10927

10 www.osha.gov/SLTC/etools/safetyhealth/mod2_sample_sh_program.html

11 www.osha.gov/Publications/OSHA3695.pdf

12 www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9805

13 www.osha.gov/dte/library/pit/trg_outline.html

14 www.osha.gov/Publications/3384small-entity-for-respiratory-protection-standard-rev.pdf

15 www.ccohs.ca/topics/programs/; www.ccohs.ca/oshanswers/hsprograms/

16 *Hazardous Materials Emergency Planning Guide*, NRT-1, 2001 www.epa.gov/oem/docs/chem/cleanNRT10_12_distiller_complete.pdf

17 *Safety and Health Requirements*, EM 385-1-1, U.S. Army Corps of Engineers, Washington, DC, November 2014. www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_385-1-1pdf

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APPENDIX A

ERGONOMICS DATA

TABLE A-1 Standing Body Dimensions for General Forces (from MIL-STD-1472G), refer to Figure A-1

	Percentile Values in Inches			
	5th Percentile		95th Percentile	
	Male	Female	Male	Female
Weight, lbs	143.7	115.8	213.8	177.8
1 Stature	65.5	63.5	73.8	69.3
2 Eye height (standing)	60.8	59.1	69.1	64.6
3 Shoulder (acromiale) height	53.5	48.4	61.2	56.9
4 Chest (nipple) height[a]	47.1	45.2	53.9	50.5
5 Elbow (radiate) height	39.7	38.4	45.7	42.8
6 Fingertip (dactylion) height	23.3	21.7	28.5	26.4
7 Waist (natural indentation) height	41.4	40.6	47.7	45
8 Crotch height	30.5	26.8	36	33.3
9 Gluteal furrow height	29.5	26.1	34.8	32.2
10 Knee (mid-patella) height	18.2	17.6	21.5	19.8
11 Calf height	12.6	10.9	15.1	14.1
12 Functional (thumbtip) reach	28.2	26.7	34.9	31.7
13 Functional reach, extended	31.7	28.9	27.1	36.3

[a]Bustpoint height for women.

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TABLE A-2 Seated Body Dimensions for General Forces (from MIL-STD-1472G), refer to Figure A-2

	Percentile Values in Inches			
	5th Percentile		95th Percentile	
	Male	Female	Male	Female
14 Vertical arm reach, sitting	52.5	50.7	59.9	56.1
15 Sitting height, erect	34.3	32.9	38.3	35.8
16 (Dimension not used)				
17 Eye height sitting, erect	29.7	28.5	34	32
18 (Dimension not used)				
19 Mid-shoulder height	23.5	22.4	27	25.3
20 Shoulder height, sitting	21.6	20	25.4	23.8
21 Shoulder-elbow length	13.5	13	15.8	14.5
22 Elbow-grip length	13.1	11.8	15.4	14.1
23 Elbow fingertip length	17.5	16	20.6	19
24 Elbow rest height	11.1	7.7	10.6	7.9
25 Thigh clearance height	5.9	5.5	7.3	7.2
26 Knee height, sitting	20.4	19.8	23.6	22
27 Popliteal height	15.6	14.8	18.6	16.9
28 Buttock-knee length	22.8	22.4	26.2	25
29 Buttock-popliteal length	18.3	18.2	21.5	20.6
30 (Dimension not used)				
31 Functional leg length	39.8	39	46	43.2

TABLE A-3 Depth and Breadth Dimensions for General Forces (from MIL-STD-1472G), refer to Figure A-3

	Percentile Values in Inches			
	5th Percentile		95th Percentile	
	Male	Female	Male	Female
32 Chest depth[b]	8.6	8.2	11.1	11.1
33 Buttock depth	8.6	7.7	11	10.7
34 Chest breadth	10.9	9.8	14.5	12.6
35 Hip breadth, standing	12.6	12.6	15.1	15.3
36 Shoulder (bideltoid) breadth	16.5	15	21.1	18.6
37 Forearm-forearm breadth	19.3	16.3	42.2	21.4
38 Hip breadth, sitting	12.2	13.3	16.1	17

[b]Bust depth for women.

TABLE A-4 Circumferences and Surface Dimensions for General Forces (from MIL-STD-1472G), refer to Figure A-4

	Percentile Values in Inches			
	5th Percentile		95th Percentile	
	Male	Female	Male	Female
40 Neck circumference	13.9	11.5	16.4	14.4
41 Chest circumference[c]	35.9	32.2	43.7	41.1
42 Waist circumference (natural indentation)	29.6	25.3	38.7	33.2
43 Hip (buttock) circumference, standing	35.8	35.1	42.8	43.2
44 (Dimension not used)				
45 Vertical trunk circumference, standing	59.3	58.3	69.7	66.4
46 (Dimension not used)				
47 Arm circumference	16.1	13.2	19.6	16.2
48 Biceps circumference, flexed	11.7	9.8	14.7	12.8
49 Elbow circumference, flexed	10	8.7	11.8	11.8
50 Forearm circumference, flexed	10.4	9.1	13.2	11
51 Wrist circumference	6.2	5.6	7.4	6.4
52 Upper thigh circumference	19.3	20.3	26.2	26.4
53 Calf circumference	12.9	12.4	16.6	15.4
54 Ankle circumference	7.9	7.3	9.5	9.2
55 Waist (natural indentation) - back length	14.7	13.6	17.8	17.4
56 Waist (natural indentation) - front length	12.2	10.8	15.1	14.3

[c]Bust circumference for women.

TABLE A-5 Hand and Foot Dimensions for General Forces (from MIL-STD-1472G), refer to Figure A-5

	Percentile Values in Inches			
	5th Percentile		95th Percentile	
	Male	Female	Male	Female
57 Hand length	6.9	6.5	8.3	7.9
58 Palm length	3.8	3.5	4.6	4.3
59 Hand breadth	3.2	2.7	3.9	3.4
60 Hand circumference	7.8	6.6	9.0	7.9
61 (Dimension not used)				
62 Foot length	9.7	9.2	11.5	10.4
63 Instep length	7.0	6.5	8.4	7.7
64 Foot breadth	3.5	3.3	4.3	3.9
65 Foot circumference	9.0	8.1	10.7	9.5
66 Heel-ankle circumference	12.3	11.1	14.3	12.9

TABLE A-6 Arm, Hand and Thumb-Finger Strength for 5th Percentile Male (from MIL-STD-1472G), refer to Figure A-6

(1)	Arm Strength (lb)											
	(2) Pull		(3) Push		(4) Up		(5) Down		(6) In		(7) Out	
Degree of Elbow Flexion	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
90 deg (flexion)	50	52	42	50	9	14	13	17	8	14	13	20
60 deg (flexion)	42	56	30	42	15	18	18	20	8	15	15	20
30 deg (flexion)	34	42	26	36	17	24	21	26	10	15	20	22
0 deg (neutral)	32	37	22	36	17	20	21	26	10	16	16	18
30 deg (extension)	26	24	22	34	15	20	18	20	12	17	17	20

	Hand and Pinch Strength (lb)			
	(8) Hand Grip		(9)	(10)
Degree of Shoulder Flexion/Extension Grip	Left	Right	Palmer Pinch Grip (Thumb Pad to Index & Middle Finger Pads)	(Thumb Tip to Index Finger) Tip Pinch Grip
Momentary Hold	56	59	13	13
Sustained Hold	33	35	8	8

TABLE A-7 Standard Computer Workstation Dimensions (from MIL-STD-1472G), refer to Figure A-7

Dimensions			Fixed/ Minimum, Inches	Adjust
Armrest	A	Length	10	
	B	Width	2	
	C	Height	8.5	7.5 to 11 in
	D	Separation	18	
Seat Pan	E	Width	16	
	F	Height	15	Seat height shall be adjustable from the minimum height up to 5 in in increments of no more than 1 in.
	G	Depth	15	Up to 17 in
		Angle from horizontal		5 degrees preferred
		Pan-backrest angle		35 to 39.3 in
Backrest	H	Space	6	Full backrest with no space between seat pan and bottom of backrest is preferred.
	I	Height	15	Backrest height shall be adjustable unless it is solid from seat pan to minimum height shown. Adjustments shall be in increments no greater than 1 in.
	J	Width	16	18 in preferred
Dimensions			Minimum, Inches	Preferred
Workspace	O	Kneehole depth (at knee height)	15	
		Kneehole depth (at deck level)	23.5	
	P	Kneehole width	20	24 in
	Q	Kneehole height	25	
	R	Desk to wall	32	
	S	Chair to wall	15	
	T	Desk width	54	
		Work surface width	24	
	U	Height of work surface keyboard (adjustable)		24 to 28 in independent adjustable keyboard support surface
		Height of work surface keyboard (fixed)	30	Fixed keyboard support surface, e.g., desktop
	V	Desk depth	30	36 in
		Work surface depth	24	30 in

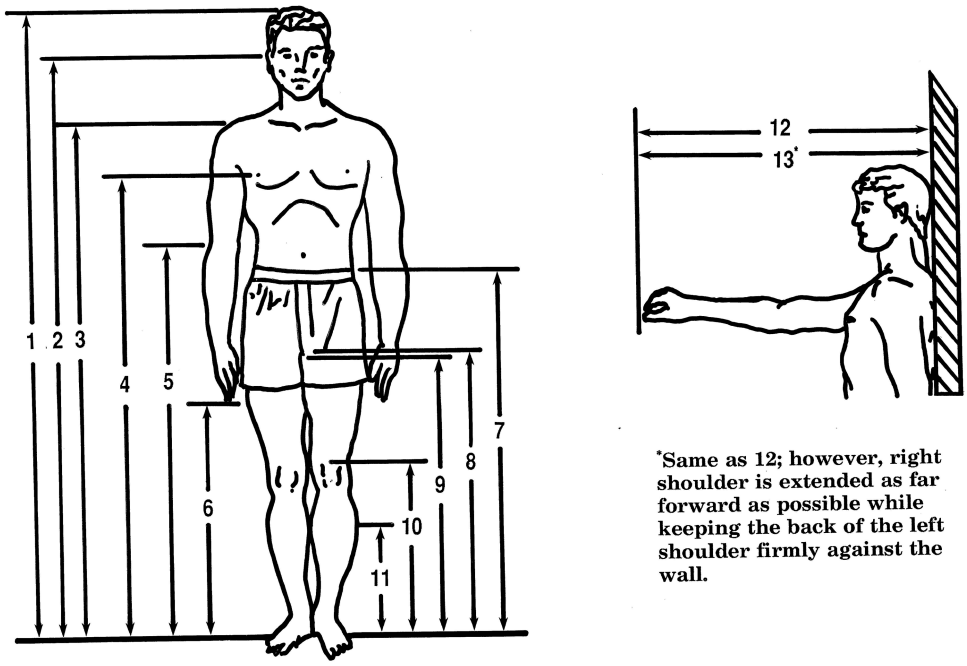


Figure A-1. Standing body dimensions. (From MIL-STD-1472G.)

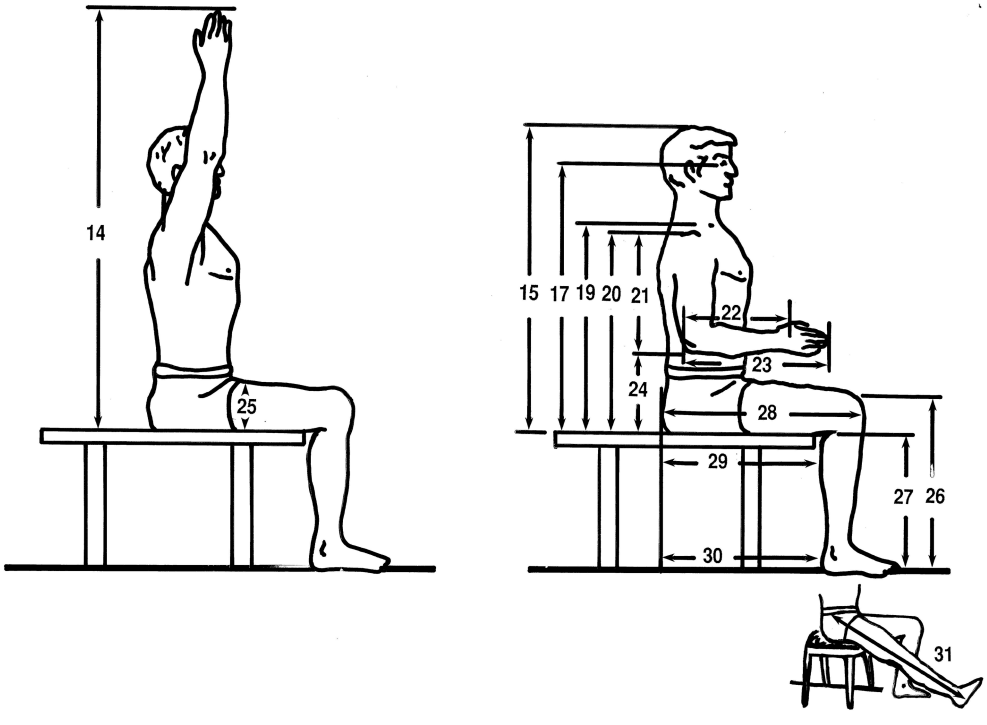


Figure A-2. Seated body dimensions. (From MIL-STD-1472G.)

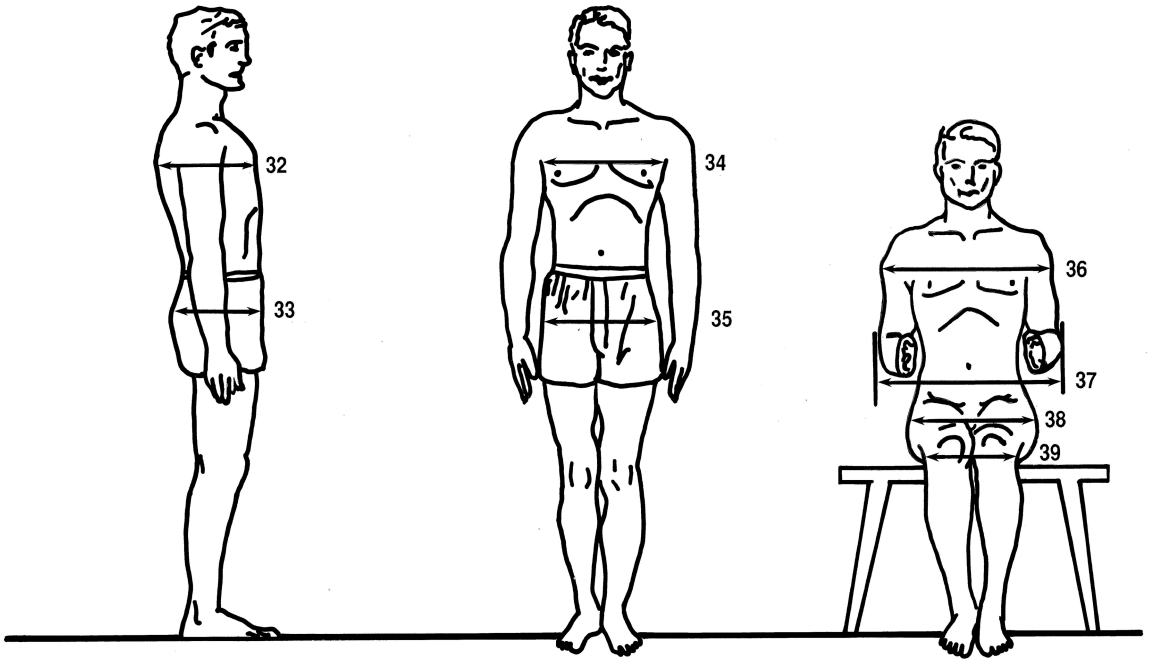


Figure A-3. Body depth and breadth dimensions. (From MIL-STD-1472G.)

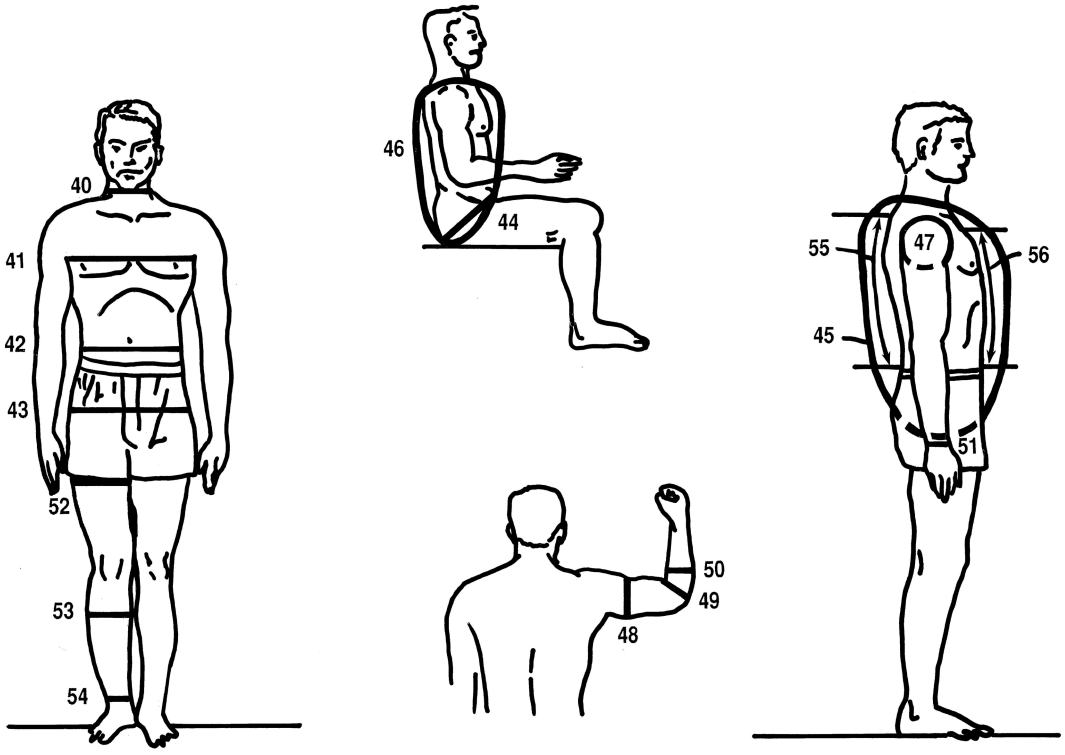


Figure A-4. Body circumferences and surface dimensions. (From MIL-STD-1472G.)

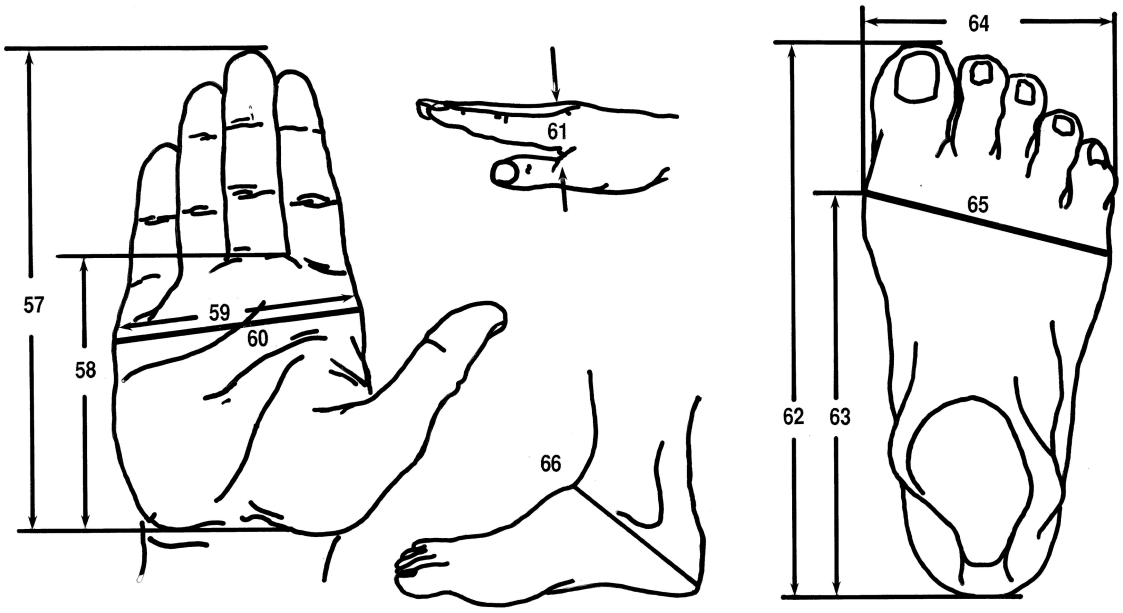


Figure A-5. Hand and foot dimensions. (From MIL-STD-1472G.)

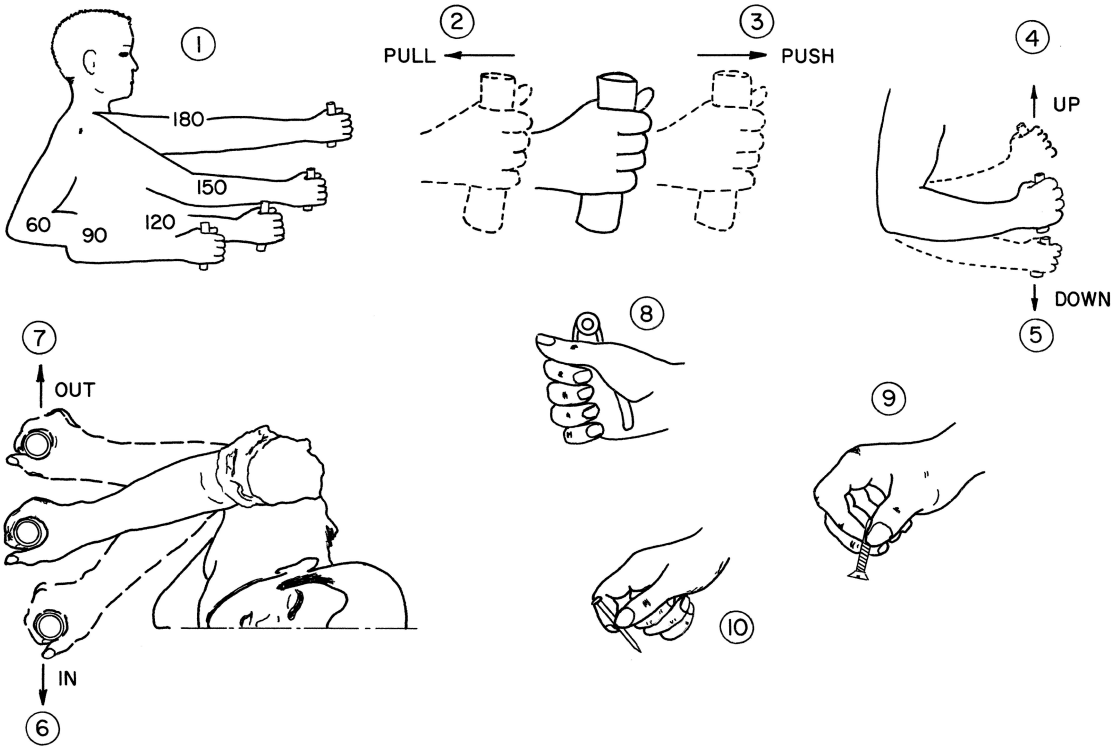


Figure A-6. Diagrams for arm, hand and thumb-finger strength data. (From MIL-STD-1472G)

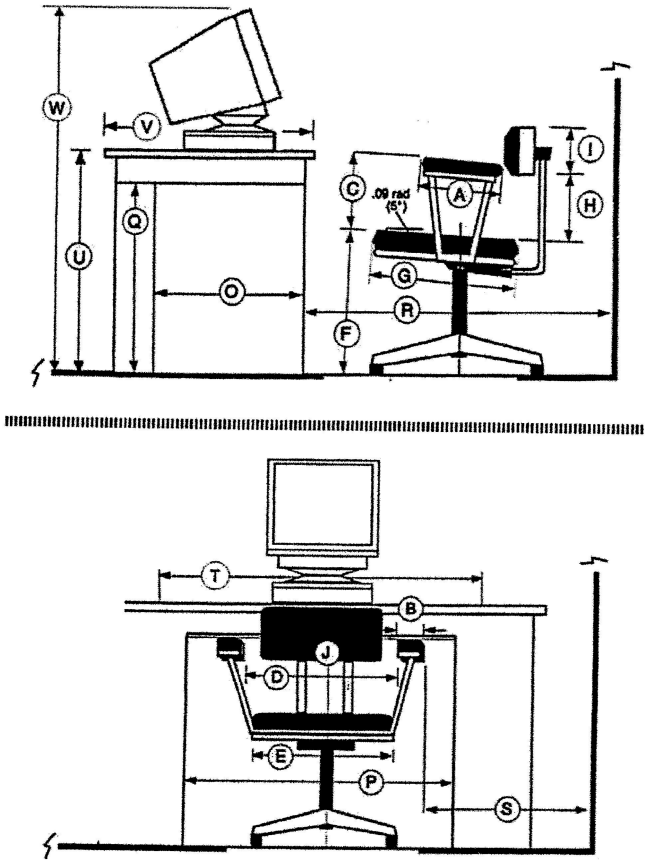


Figure A-7. Standard computer workstation dimensions. (From MIL-STD-1472G.)

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