CHAPTER 3

Concepts of Hazard Avoidance

Hazards involve risk or chance, and these words deal with the unknown. As soon as the unknown element is eliminated, the problem is no longer one of safety or health. For example, everyone knows what would happen if someone jumped off a 10-story building. Immediate death would be virtually a certainty, and such an act is not properly described as unsafe; it is described as suicidal. However, to work on the roof of a 10-story building with no intention of falling off becomes a matter of safety. Workers without fall protection on an unguarded rooftop of a building are exposed to a recognized hazard. This is not to say that such workers will be killed or even to say that they will come to any harm whatsoever, but there is that chance, that unknown element.

Dealing with the unknown makes the job of the safety and health manager a difficult one. If the safety and health manager pushes for a capital investment to enhance safety or health, who is able to *prove* later that the investment was worthwhile? Improved injury and illness statistics help and may look impressive, but they do not actually prove that the capital investment was worthwhile because no one really knows what the statistics would have shown had the investment *not* been made. It is in the realm of the unknown.

Since safety and health deal with the unknown, there is no step-by-step recipe for eliminating hazards within the workplace. Instead, there are merely concepts or approaches to take to whittle away at the problem. All of the approaches have merit, but none is a panacea. Drawing on their own strengths, different safety and health managers tend to concentrate on certain favorite approaches familiar to them. The objective of this chapter is to present various approaches so that the safety and health manager will have a variety of tools, not just one or two, to deal with the unknown elements of worker safety and health. Both the good and the bad will be discussed for each approach. The good is often obvious or taken for granted. However, the drawbacks of each approach must be squarely faced too, so that safety and health managers can see the limitations and draw on the strengths of each approach to accomplish their missions.

THE ENFORCEMENT APPROACH

This is the approach initially taken by OSHA, but OSHA was certainly not the first to use it. Safety rules with penalties for breaking them have existed almost since people first began to deal with risks. The pure enforcement approach says that, since people neither assess hazards properly nor take prudent precautions, they should be given rules to follow and be subject to penalties for breaking those rules.

The enforcement approach is simple and direct; there is no question that it has an impact. The enforcement must be swift and sure and the penalties sufficiently severe. If these conditions are met, people will follow rules to some extent. Using the enforcement approach, OSHA has without doubt forced thousands of industries to comply with regulations that have changed workplaces and made millions of jobs safer and more healthful. The preceding statement sounds like a glowing success story for OSHA, but the reader should know that the enforcement approach has failed to do the whole job. It is difficult to see any general improvement in injury and illness statistics as a result of enforcement, although some categories, such as trenching and excavation cave-ins, have shown marked improvement. Despite its advantages, there are some basic weaknesses in the enforcement approach, as the statistics suggest. These weaknesses will now be examined.

At the foundation of any enforcement approach lies a set of mandatory standards. Mandatory standards must be worded in absolutes, such as "always do this" or "never do that." The wording of complicated exceptions can alleviate the problem somewhat, but requires the anticipation of every circumstance to be encountered. Within the framework of the stated scope of the standard, recognizing all exempt situations, each rule must be absolutely mandatory to be enforceable. However, mandatory language employing the words *always* and *never* is really inappropriate when dealing with the uncertainties of safety and health hazards. To see how this is true, consider Case Study 3.1.

CASE STUDY 3.1

Suppose that a properly grounded electrical appliance used for the resuscitation of injured employees is equipped with a three-prong plug. However, in the midst of an emergency, it is discovered that the wall receptacle is the old, ungrounded, two-hole variety. With no adapter in sight and an employee in desperate need of the appliance, who would not bend back or cut off the grounding plug and proceed to save the employee's life?

Of course, this example states an extreme case, and we must be "reasonable" and use our "professional judgment," but in the arena of enforcement and mandatory standards, who is going to say what is "reasonable"? Everyone knows what is reasonable in such an extreme case, but countless borderline cases occur every day in which it is not certain whether the proper course of action is to violate or not to violate the rule. Consider Case Study 3.2.

CASE STUDY 3.2

A dangerous fire was in progress as flammable liquids were burning in tanks. To shut off the source of fuel, a thinking employee quickly turned off the adjacent tank valves to avert a more dangerous fire that could have cost many lives, not to speak of property damage. Did the employee receive a medal for his meritorious act? The answer is no. Instead, the company received an OSHA citation because the employee was not wearing gloves! The valves were hot, and because the employee went ahead and closed the valves, burning his hands, the company was issued a citation.

If a government agency will issue a citation for failure to wear gloves while closing a valve in an emergency, who will have the courage to "be reasonable" and to go ahead and act even if a violation is the consequence? A strikingly similar case is described in Case Study 3.3.

CASE STUDY 3.3

In a trench cave-in accident in Boise, Idaho, a worker was buried and coworkers, "Good Samaritans," bravely jumped into the trench in the emergency to attempt to free the buried worker. OSHA responded by fining the company $8000 because of the humanitarian response of the rescue workers to the emergency. This action was ridiculed by some U.S. Senators, who awarded OSHA the infamous "Red Tape Award" for issuing the citation (OSHA, 1993).

Although OSHA later rescinded the fines in the Idaho trench rescue case, one can see that the enforcement approach leads to problems when it is the only response to dealing with a safety or health hazard. Sometimes a fine is a negative and inappropriate response in a vain attempt to place blame after the fact when an accident has occurred. In the face of a pure enforcement approach, many industry employees and employers alike will gradually retreat to a defensive position, failing to achieve production targets, and blaming their lack of productivity on the government.

As stated earlier, OSHA did not invent the enforcement approach for dealing with hazards. Other mandatory safety rules and laws are familiar to everyone. Sometimes overzealous and oppressive rules can destroy themselves by alienating the very persons they are intended to protect. A notorious example is the mandatory helmet law for motorcycle riders. The helmet manufacturers can present impressive statistics that show how helmets save lives, at least in some accidents. Such statistics should be a strong motivation to motorcyclists to wear helmets. However, in certain situations, the use of a helmet has disadvantages that may cause motorcyclists to hate the law that requires them to wear a helmet *always*. Thus, it is illegal to give a friend a trial ride around the block without obtaining an extra helmet for the passenger for that one ride. If a temporary skin rash or scalp treatment prevents an operator from wearing the helmet for a day or two, he or she must not ride, even if the motorcycle is the sole means of transportation. Where to put the helmet during a brief stop can also become extremely awkward in some situations. One motorcyclist in Houston became so frustrated that he complied with the letter of the law while he defied its spirit by riding his motorcycle around and about the city wearing his helmet on his elbow!

Despite the strong negative reaction of some motorcyclists to the helmet law, the public is coming around to the understanding that helmets do save lives, not only on motorcycles, but on bicycles as well. Helmet usage while riding bicycles as well as motorcycles has become common practice in the twenty-first century. Helmet laws may have initially blazed the trail, but the psychological approach of convincing riders that the helmet is a worthwhile precaution has made the difference in actual acceptance of the practice of wearing helmets while riding a motorcycle or bicycle. We now turn to the psychological approach for its contribution to the concepts of hazard avoidance.

THE PSYCHOLOGICAL APPROACH

Contrasted with the enforcement approach is an approach that attempts to reward safe behaviors. This is the approach employed by many safety and health managers and may be identified as the psychological approach. The familiar elements of the psychological approach are posters and signs reminding employees to work safely. A large sign may be at the front gate of the plant displaying the number of days since a lost-time injury. Safety meetings, departmental awards, drawings, prizes, and picnics can be used to recognize and reward safe behaviors.

Religion versus Science

The psychological approach emphasizes the religion versus the science of safety and health. Safety meetings at which the psychological approach is used are typified by attempts at persuasion, sometimes called *pep talks.* The idea is that employees can be rewarded into wanting to have safe work habits. Peer pressure can be brought to bear on an employee when the entire department may suffer if one person has an injury or an illness.

Top Management Support

The psychological approach is very sensitive to the support of top management. If such support is absent, the approach is very vulnerable. Recognition pins, certificates, and even monetary prizes are small rewards if workers feel that to win these rewards they are not pursuing the real goals of top management.

Workers are able to sense the extent of management's commitment to safety by the day-to-day decisions it makes, not by written proclamations that everyone should "be safe." A rule requiring safety glasses to be worn in the production area is undermined when top management does not wear safety glasses when visiting the production floor. If safe practices are ordered to be cast aside when production must be expedited to fill an order on time, workers find out just how much worker safety and health mean to top management. Most safety and health managers will want to get a written endorsement of the plant safety program from top management. However, unless top management really understands and believes in the safety and health program, the written endorsement is not very valuable. The true orientation of top management will soon show through. Safety and health managers should beware of this pitfall when seeking such a written endorsement.

Worker Age

New workers, especially new young workers, are particularly influenced by the psychological approach to safety and health. Workers in their late teens or early twenties enter the workplace having recently emerged from a social structure that places a great deal of importance on daring and risk taking. These new workers are watching supervisors and more experienced coworkers to determine what kind of behavior or work habits earn respect in the industrial setting. If their older, more experienced peers wear respirators or ear protection, the young workers may also adopt safe habits. If highly respected coworkers laugh at or ignore safety principles, young workers may get off to a very bad start, never taking safety and health seriously.

In fairness to young workers, there is a complacency factor in older, more experienced workers that sometimes leads to tragic accidents at the end of the older worker's career. Case Study 3.4 tells the sad story of a worker who took an extra shift before a vacation prior to his retirement.

CASE STUDY 3.4

EXPERIENCED WORKER KILLED

On an extra weekend shift, a steel mill worker was removing a 5-ton piece of equipment using a crane. The equipment was attached to the overhead crane, but did not lift properly because one of the equipment "hold-downs" was still attached. This caused the equipment to cock to one side. The worker saw the problem and went into the mill to detach the hold-down. Since the lift was under crane tension, the release of the hold-down caused the load to swing unexpectedly. The worker was crushed in a pinch point between the mill stand and the hold-down. The employee was 62 years old and had been employed in the industry for 33 years. Tragically, he did not quite make it to retirement.

Accident reports confirm that a large percentage of injuries are caused by unsafe acts by workers. This fact emphasizes the importance of the psychological approach in developing good worker attitudes toward safety and health. This approach can be bolstered by training them in the hazards of specific operations. Once the subtle hazards are made known to workers, who otherwise would not know about these hazards, the development of safe attitudes becomes less difficult.

Safety from the Ground Up

In the twenty-first century, increased attention has been placed upon getting employees to recognize hazards themselves and drive safety from the ground up. While recognizing the importance of top management support to any psychological approach, there is still a need to get employees themselves to recognize the gravity of the hazards to which they are exposed. What will employees do when management is not looking, especially on the late night shifts? If employees can come to understand and take seriously the hazards of unsafe operation, the psychological approach is simple and effective. The workers themselves will drive the safety program from the ground up.

Chapter 2 recognized the importance of committees to the safety and health function. Recently, many firms are beginning to deploy safety and health committees composed of and led solely by the employees themselves (excluding management). Rather than analyze processes, these teams observe fellow employees and their behavior, comment on potentially safe and unsafe behaviors, and train their peers on safe practices. Since this feedback comes from one equal to another, it is usually better received.

THE ENGINEERING APPROACH

For decades, safety engineers have attributed most workplace injuries to unsafe worker acts, not unsafe conditions. The origin of this thinking has been traced back to the great pioneering work in the field by the late H. W. Heinrich (Heinrich, 1959), the first safety engineer so recognized. Heinrich's studies resulted in the widely known ratio 88:10:2.

Unsafe acts	88%
Unsafe conditions	10%
Unsafe causes	2%
Total causes of workplace accidents	100%

Recently, Heinrich's ratios have been questioned, and efforts to recover Heinrich's original research data have produced sketchy results. The current trend is to give increasing emphasis to the workplace machinery, environment, guards, and protective systems (i.e., the *conditions* of the workplace). Accident analyses are probing more deeply to determine whether incidents that at first appear to be caused by "worker carelessness" could have been prevented by a process redesign. This development has greatly enhanced the importance of the "engineering approach" to dealing with workplace hazards.

Three Lines of Defense

From the profession has emerged a definite preference for the engineering approach when dealing with health hazards. When a process is noisy or presents airborne exposures to toxic materials, the firm should first try to redesign or revise the process to "engineer out" the hazard. Thus, engineering controls receive first preference in what might be called *three lines of defense* against health hazards. These are identified as follows:

1. Engineering controls
2. Administrative or work-practice controls
3. Personal protective equipment

The advantages of the engineering approach are obvious. Engineering controls deal directly with the hazard by removing it, ventilating it, suppressing it, or otherwise rendering the workplace safe and healthful. This removes the necessity of living with the hazard and minimizing its effects as contrasted with the strategies of administrative controls and the use of personal protective equipment. This preference of strategies will be considered again in Chapters 10 and 12.

For an example of the three lines of defense concept, consider the problem of chronic exposure to noise that can damage the workers' hearing. The first and preferable line of defense would be to find some way to eliminate the source of the noise exposure. This might be a process change that results in quieter equipment or it could be the isolation of the equipment in a room where employees are not exposed to the noise hazard. An administrative or work-practice control would be to schedule employees on a rotation basis so that the exposure to the excessive noise would be limited to short durations. This approach might be combined with the engineering approach of isolating the noise source in a separate room, accessed on a short-term basis only when necessary by essential personnel. The last resort should be personal protective equipment or hearing protectors, which depends for its effectiveness upon employee actions to actually wear the protective equipment and wear it properly.

Safety Factors

Engineers have long recognized the chance element in safety and know that margins for variation must be provided. This basic principle of engineering design appears at various places in safety standards. For example, the safety factor for the design of scaffold components is 4:1. For overhead crane hoists, the factor is 5:1, and for scaffold *ropes*, the factor is 6:1 (i.e., scaffold ropes are designed to withstand six times the intended load).

The selection of safety factors is an important responsibility. It would be nice if all safety factors could be 10:1, but there are tradeoffs that make such large safety factors unreasonable, even infeasible, in some situations. Cost is the obvious, but not the only, tradeoff. Weight, supporting structure, speed, horsepower, and size are all factors that may be affected by selecting too large a safety factor. The drawbacks of large safety factors must be weighed against the consequences of system failure in order to arrive at a rational decision. There are many degrees of difference between situations when evaluating the consequences of system failures. Compare the importance of safety factors in the Kansas City hotel disaster[1] of 1981 to a failure in which the only loss is some material or damaged equipment. Obviously, the former situation should employ a larger safety factor than the latter. Selection of safety factors depends on the evaluation or classification of degree of hazard, a subject that is treated in depth later in this chapter.

Fail-Safe Principles

Besides the engineering principle of safety factors, there are additional principles of engineering design that consider the consequences of component failure within

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[1] Two skywalks collapsed in the crowded multistory lobby of the Hyatt Regency Hotel in Kansas City, Missouri on July 17, 1981, killing 113 persons.

the system. These principles are labeled here as *fail-safe principles*, and three are identified:

1. General fail-safe principle
2. Fail-safe principle of redundancy
3. Principle of worst case

Each of these principles will be considered here, and their applications will appear again and again in subsequent chapters dealing with specific hazards.

General Fail-Safe Principle

> The resulting status of a system, in the event of failure of one of its components, shall be in a safe mode.

Systems or subsystems generally have two modes: active and inert. With most machines, the inert mode is the safer of the two. Thus, product safety engineering is usually quite simple: If you "pull the plug" on the machine, it cannot hurt you. However, the inert mode is not always the safer mode. Suppose that the system is a complicated one, with subsystems built in to protect the operator and others in the area in the event of a failure within the system. In this case, pulling the plug to disconnect the machine might deactivate the safety subsystems so essential to protecting the operator and others in the area. In the case of such a system, disconnecting the power might render the system more unsafe than when the power is on. Design engineers need to consider the general fail-safe principle so as to ensure that a failure within the system will result in a safe mode. Thus, it may be necessary to provide backup power for the proper functioning of safety subsystems. Case Studies 3.5 and 3.6 will illustrate this concept.

CASE STUDY 3.5

An electric drill has a trigger switch that might be continuously depressed to operate the drill. The trigger switch is loaded with a spring, so that if some failure (on the part of the operator in this case) results in the release of the trigger, the machine will return to a safe mode (off, in this case). Such a switch is often called a *deadman control*. This example illustrates the common situation in which the inert state of the system is the safer one.

CASE STUDY 3.6

This example illustrates the more uncommon situation in which the inert state of the system is the more dangerous state. Consider an automobile with power steering and power brakes. When the engine dies, both steering and braking may become very difficult; so at least as far as these subsystems are concerned, the inert state is more dangerous than the active one.

As will be seen in later chapters, industrial systems have characteristics similar to those described in the foregoing case studies. Sometimes safety standards specify that system failures be accommodated in such a way that subsystems for safety will continue to be operative.

The general fail-safe principle is the one that embodies the literal meaning of the term *fail safe*. However, industry and technology often associate another concept with the term *fail safe*, and that is the concept of *redundancy*.

Fail-Safe Principle of Redundancy

> A critically important function of a system, subsystem, or components can be preserved by alternate parallel or standby units.

The design principle of redundancy has been widely used in the aerospace industry. When systems are so complicated and of such critical importance as a large aircraft or a space vehicle, the function is too important to allow the failure of a tiny component to bring down the entire system. Therefore, engineers back up primary subsystems with standby units. Sometimes, dual units can be specified right down to the component level. For extremely critical functions, three or four backup systems can be specified. In the field of occupational safety and health, some systems are seen as so vital as to require design redundancy. Mechanical power presses are an example.

Still another fail-safe design principle is the principle of *worst case*.

Principle of Worst Case

> The design of a system should consider the worst situation to which it may be subjected in use.

This principle is really a recognition of *Murphy's law*, which states, "If anything can go wrong, it will." Murphy's law is no joke; it is a simple observation of the result of chance occurrences over a long period of time. Random events that have a constant hazard of occurrence are called *Poisson processes*. The design of a system must consider the possibility of the occurrence of some chance event that can have an adverse effect on safety and health.

An application of the principle of worst case is seen in the specification of explosion-proof motors in ventilation systems for rooms in which flammable liquids are handled. Explosion-proof motors are much more expensive than ordinary motors, and industries may resist the requirement to install explosion-proof motors, especially in those processes in which the vapor levels of the substances mixed never even get close to the explosive range. However, consider the scenario presented by a hot summer day on which a spill happens to occur. The hot weather raises the vapor level of the flammable liquid being handled. A spill at such an unfortunate time dramatically increases the liquid surface exposure, which makes the problem many times worse. At no other time would the ventilation system be more important. However, if the motor is not explosion proof and is exposed to the critical concentration of vapors, a catastrophic explosion would occur as soon as the ventilation system gets switched on.

The concept of *defensive driving* is well known to all drivers and serves to explain the principle of worst case. Defensive drivers control their vehicles to the extent that they are prepared for the worst random event they can reasonably imagine.

Design Principles

Engineers have come to rely on a variety of methods or "engineering design principles" to reduce or eliminate hazards. Some of these principles are listed here to stimulate thinking of the various paths that can be taken in dealing with hazards.

1. *Eliminate* the process or cause of the hazard. Often a process has been performed over so long a period that it is erroneously considered essential to the operation of the plant. After many years of operation, a process becomes institutional and plant personnel tend to accept it without question. However, it is the duty of safety and health professionals to question old and accepted ways of doing things if these ways are hazardous. Hazards that may have been considered acceptable in the days when the process was originally designed may now be considered unacceptable. New thinking may reach a different conclusion on the question of just how critical the need is for a particular process.

2. *Substitute* an alternate process or material. If a process is essential and must be retained, perhaps it can be substituted with another method or material that is not so dangerous. A good example is the substitution of less hazardous solvents for benzene, which has been found to cause leukemia. Another example is changing a machining process to perform the machining dry, that is, without the benefit of cutting fluid. Certainly many machine tool cutting operations require cutting fluid, but for some materials and processes, cutting fluid may not be absolutely necessary and the drawbacks might outweigh the benefits.

3. Reduce or *slow down* exposure to hazardous processes or materials. It may be possible to reduce the quantity of hazardous material being used in a process. Even if the quantity used in the process cannot be reduced, perhaps the inventory of the hazardous material can be reduced while in storage. With flammable, explosive, or toxic materials, part of the danger exists while the material is in storage waiting to be processed. The same idea can be applied to the energy of a process or machine. Thus, slowing down the speed of the equipment may reduce the hazard of injury if something goes wrong. This strategy should be used judiciously because sometimes slowing down a machine makes it *more* dangerous, as will be seen in Chapter 15 in the discussion on mechanical power presses.

4. *Guard* personnel from exposure to the hazard. Perhaps a process is absolutely essential to the operation of the plant, and there is no substitute for it or for the hazardous materials that must be dealt with by it. In these cases, it is sometimes possible to control exposure to the hazard by guarding personnel from exposure to the hazard.

5. Install *barriers* to keep personnel out of the area. Contrasted with guards, which are attached to the machine or process, are independent barriers that are installed around the process or machine to keep personnel out of danger. Such barriers may seem more like an administrative function or an operational procedure, but the engineer who designs the process can specify, in particular, what barriers are needed around a process and where to place them.

6. *Warn* personnel with visible or audible alarms. In the absence of other protective design features of the system, the engineer can sometimes design the machine or process in such a way that the system warns the operator or other personnel when

exposure to a significant hazard is imminent or likely. To be effective, the alarm should be used sparingly so that the personnel do not ignore the flashing light or the beeping alarm and continue operating the process despite the exposure.

7. Use *warning labels* to caution personnel to avoid the hazard. Sometimes, an essential hazardous operation cannot be eliminated, substituted with a less hazardous process or material, or adequately guarded from personnel exposure. In these situations, at least, it is often possible to attach a warning label to the process or device that reminds personnel of hazards that are not controlled by the machine or process itself. This design approach is not as effective as the preceding approaches, because personnel may not read or heed the warning labels. Despite the limited effectiveness of warning labels, they are better than complete disregard for the hazard in the design process.

8. Use *filters* to remove exposure to hazardous effluents. Certain hazards require a different perspective on the part of the design engineer. The exhaust of dangerous effluents is an example. The engineer can sometimes design filter systems in the machine or process itself to deal with gases or dusts that may be undesirable products of the process.

9. Design *exhaust ventilation* systems to deal with process effluents. Sometimes, the undesirable products of a process are too hazardous or are impractical to filter out of the breathing air in the environment of a process. In these cases, sometimes, the process or machine design itself can include features that exhaust the harmful agents as they are being produced. Again, these features may seem to be within the purview of someone else, such as a ventilation expert or plant maintenance engineer. Nevertheless, the designer of the process itself should not overlook opportunities to incorporate these features into the original design of the process or machine.

10. Consider the *human interface*. After the more straightforward engineering principles of dealing with hazards are included in the design process, it is a good idea to once again review and identify all the interfaces of the process or machine with personnel. At what points does it become necessary for persons to interact with the machine? At these points, are personnel exposed to hazards? The human interfaces so identified should include both the equipment interfaces and the material interfaces. Each interface so identified should be checked again for possible design features that can further control hazards using the other engineering design principles enumerated in this section.

Engineering Pitfalls

It is easy to get caught up in the idea that technology can solve our problems, including elimination of workplace hazards. Certainly, an inventor of a new gadget to prevent injuries or illnesses can become quickly enamored with it and present a convincing argument that the new invention should be installed in workplaces everywhere. When standards writers are persuaded by these arguments, they often require all appropriate industries to install the new device. Several things can go wrong, however.

Recalling the case against the enforcement approach, certain unusual circumstances can make the engineering solution inappropriate or even unsafe. A good example is the use of spring-loaded cutoff valves in air lines for compressed-air tools. The purpose of the cutoff valve is to prevent hose whip action by stopping the flow of air if the tool accidentally separates from the hose. The sudden flow of air overcomes the spring-loaded valve and closes it, stopping the flow. The problem comes when several tools are operated from the same main hose and airflow reaches a maximum even during normal use. The cutoff then becomes a nuisance and impedes production.

A second problem with the engineering approach is related to the first: Workers remove or defeat the purpose of engineering controls or safety devices. The most obvious example is the removal of guards from machines. Before faulting the worker for such behavior, take a close look at the guard design. Some guards are so awkward that they make the work nearly impossible. Some machine guards are so impractical that they conjure up doubts about the motives of the equipment manufacturer. There is a legal motivation to install an impractical guard on a new machine so that users will take the guard off before putting the machine in service. When the user modifies a machine by removing a guard, the manufacturer is absolved of guilt for any accident that later occurs, but that might reasonably have been prevented by the guard.

An irony of the engineering approach is that, if the engineered system does not do the job for which it was intended, it can do more harm than good by engendering a false sense of security (Case Study 3.7).

CASE STUDY 3.7

A FALSE SENSE OF SECURITY

A printing press operator was proudly demonstrating a new printing press to his family at an open house intended to display the state-of-the-art safety devices engineered into the new equipment. One of the high-tech features was a photoelectric sensing device that was engineered to detect any object (such as the operator's hands) that had violated the danger zone at the in-running nip point to the printing rolls. The system was designed to immediately stop the rolls whenever an object was sensed. So proud of the design feature of the system was the operator that he demonstrated by thrusting his hand repeatedly into the danger zone. Ultimately, he succeeded in beating the system, and the printing press did indeed amputate the end of one of his fingers. Incredible as this case study may seem, this incident actually happened. One could question the judgment of the operator in tempting the machine in such a foolish way, but the tendency exists to trust the engineering implicitly. Thus, workers are exposed to hazards due to the false sense of security that engineering systems sometimes engender.

Such false sense of security can even lead to new operator procedures that depend on the safety device to control the operation so that the work can be hastened. The best example that comes to mind is the hoist limit switch on an overhead crane. If the hoist load block approaches too close to the bridge, the hoist limit switch is tripped, shutting off the hoist motor. The idea sounds good, but the operator can take advantage of the device by *depending* on the switch to stop the load during normal operation. The hoist limit switch is not intended as an operating control, but workers can and do use it that way. The only defense against such use appears to be proper training and safe attitudes on the part of the operator, that is, the psychological approach.

Finally, the engineered system can sometimes cause a hazard, as illustrated in the example that follows in which a pneumatic press ram pinned an operator's hand on the *upstroke* (see Figure 3.1). The press was equipped with a two-hand control that was designed for safety's sake not to allow the press to be actuated except by both hands of the operator. Ironically, the two-hand control created a hazard. This press was later redesigned to place a shield in front of the ram so that the operator would be unable to reach into the area above the ram.

Foot controls for machines provide a good example of the conflicts that arise between the hazards that engineering controls are designed to prevent and the hazards that they create. Accidental tripping is a problem with foot controls, so engineers have fashioned enclosures into which the operator must insert his or her foot before stepping on the control itself. The problem with these enclosures is that they make the process of activating the foot trip more complicated. More attention is required of the operator to move the foot in the right ways to get it inside the enclosure and then operate the pedal. Supposedly, this is good because then a careless motion will not accidentally actuate the machine. However, because of the sometimes awkward additional motions that the enclosure requires, some operators position their feet so that they can keep one foot on the pedal at all times—so-called "riding the pedal." Unfortunately, riding the pedal increases the likelihood that the operator will accidentally trip the machine, the very hazard that the foot pedal enclosure was intended to prevent. This problem has been studied extensively by Triodyne, Inc. (Barnett, 1997).

As another example, robots are being used to work in hot, noisy environments, to lift heavy objects, and to otherwise serve in places where humans might be injured or suffer health hazards. Most industrial robots are simply mechanical arms programmed by computer to feed material to machines or to do welding. However, the mindless swinging of these mechanical arms can cause injury to workers who get in the path of the robot. The irony is that a hazard is created by the robot, the very purpose of which was

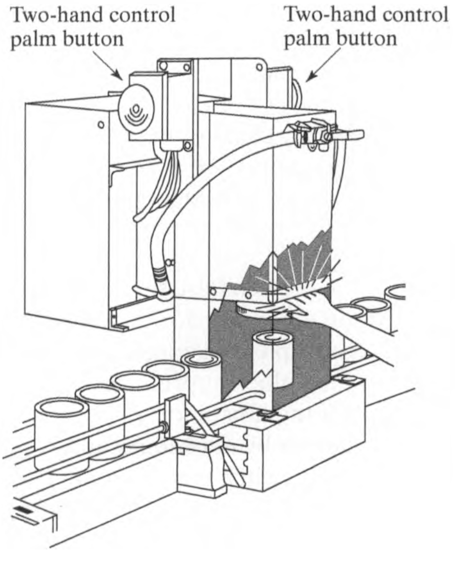

FIGURE 3.1

Pneumatic press ram pins operator's hand on the upstroke; two-hand control safety device prevents the operator from reactivating the press to release his or her hand.

to reduce hazards. One solution is to make the robot more sophisticated, giving it sensors to detect when a foreign object or person is in its path. Another solution is simply to install guardrails around the robot or otherwise keep personnel out of the danger zone.

In summary, the engineering approach is a good one and deserves the recent emphasis it is receiving. However, there are pitfalls, and the safety and health manager needs a certain sophistication to see both the advantages and disadvantages in proposed capital equipment investments in safety and health systems. Upon review of the preceding examples of engineering pitfalls, it can be seen that almost every problem can be dealt with if some additional thought is given to the design of the equipment or its intended operation. The conclusion to be reached is that engineering can solve safety and health problems, but the safety and health manager should not naïvely assume that the solutions will be simple.

THE ANALYTICAL APPROACH

The analytical approach deals with hazards by studying their mechanisms, analyzing statistical histories, computing probabilities of accidents, conducting epidemiological and toxicological studies, and weighing costs and benefits of hazard elimination. Many, but not all, analytical methods involve computations.

Accident Analysis

Accident and incident (near miss) analysis is so important that it already has been discussed extensively in Chapter 2. No safety and health program within an industrial plant is complete without some form of review of mishaps that have actually occurred. The subject is mentioned again here to classify it as within the analytical approach and to show its relationship to other methods of hazard avoidance. Its only drawback is that it is *a posteriori*, that is, the analysis is performed after the fact, too late to prevent the consequences of the accident that has already happened. However, the value of the analysis for future accident prevention is critical.

Accident analysis is not used nearly enough to assist in the other approaches to hazard avoidance. The enforcement approach would be much more palatable to the public if the enforcing agency would spend more time analyzing accident histories. That way, citations would be written only for the most important violations. The psychological approach could also be strengthened a great deal by substantiating persuasive appeals with actual results of accidents. The engineering approach needs accident analysis to know where the problems are and to design a solution to deal with all of the accident mechanisms.

Failure Modes and Effects Analysis

Sometimes a hazard has several origins, and a detailed analysis of potential causes must be made. Reliability engineers use a method called *failure modes and effects analysis* (FMEA) to trace the effects of individual component failures on the overall, or "catastrophic," failure of equipment. Such an analysis is equipment oriented instead of hazard oriented. In their own interest, equipment manufacturers sometimes perform an FMEA before a new product is released. Users of these products can sometimes benefit from an examination of the manufacturer's FMEA in determining what caused a particular piece of equipment to fail in use.

FMEA becomes important to the safety and health manager when the failure of a piece of equipment can result in an industrial injury or illness. If a piece of equipment is critical to the health or safety of employees, the safety and health manager may desire to request a report of an FMEA performed by the manufacturer of, or potential bidder for, the equipment. In practice, however, FMEA is usually ignored by safety and health managers until *after* an accident has occurred. Certainly, safety and health managers should at least know what the initials FMEA represent so that they are not dazzled by the term in the courtroom should equipment manufacturers use it to defend the safety of their products.

One beneficial way of using FMEA *before* an accident occurs is in preventive maintenance. Every component of equipment has some feasible mechanism for eventual failure. To simply use equipment until it eventually fails can sometimes have tragic consequences. Consider, for example, the wire rope on a crane, or the chain links in a sling, or the brakes on a forklift truck. The FMEA can direct attention to critical components that should be set up on a preventive maintenance schedule that permits parts to be inspected and replaced *before* failure.

To strengthen understanding of the method of FMEA, let us consider an example. A good candidate for analysis is a breathing respirator. There are various ways that a respirator can fail to do its job. One mode of failure is the loading up of the filter cartridge. It is necessary to examine the ways that the respirator will be used to determine whether this mode of failure will lead to catastrophic consequences or simply require a routine changing of the filter element. If the atmosphere is an acute danger to the respirator users, the loading up of the cartridge may lead to unconsciousness and subsequently death to the victims who are unable to take appropriate corrective action on their own. On the other hand, if the atmosphere is a serious danger, but only during extended exposures, as with many low-level carcinogens, the failure mode may lead to a relatively benign situation in which the user notices the smell of the loaded respirator cartridge and changes it in accordance with procedure. The FMEA can be used then to determine which of several types of respirators is appropriate for the application. This example will be better understood when various types of respirators are examined more thoroughly in Chapter 12.

Fault-Tree Analysis

A very similar, but more general, method of analysis than FMEA is *fault-tree analysis*. While FMEA focuses on component reliability, fault-tree analysis concentrates on the end result, which is usually an accident or some other adverse consequence. Accidents are caused at least as often by procedural errors as by equipment failures, and fault-tree analysis considers all causes—procedural or equipment. The method was developed by Bell Laboratories under contract with the U.S. Air Force in the early 1960s. The objective was to avoid a potential missile system disaster.

The term *fault tree* arises from the appearance of the logic diagram that is used to analyze the probabilities associated with the various causes and their effects. The leaves and branches of the fault tree are the myriad individual circumstances or events that can contribute to an accident. The base or trunk of the tree is the catastrophic accident or

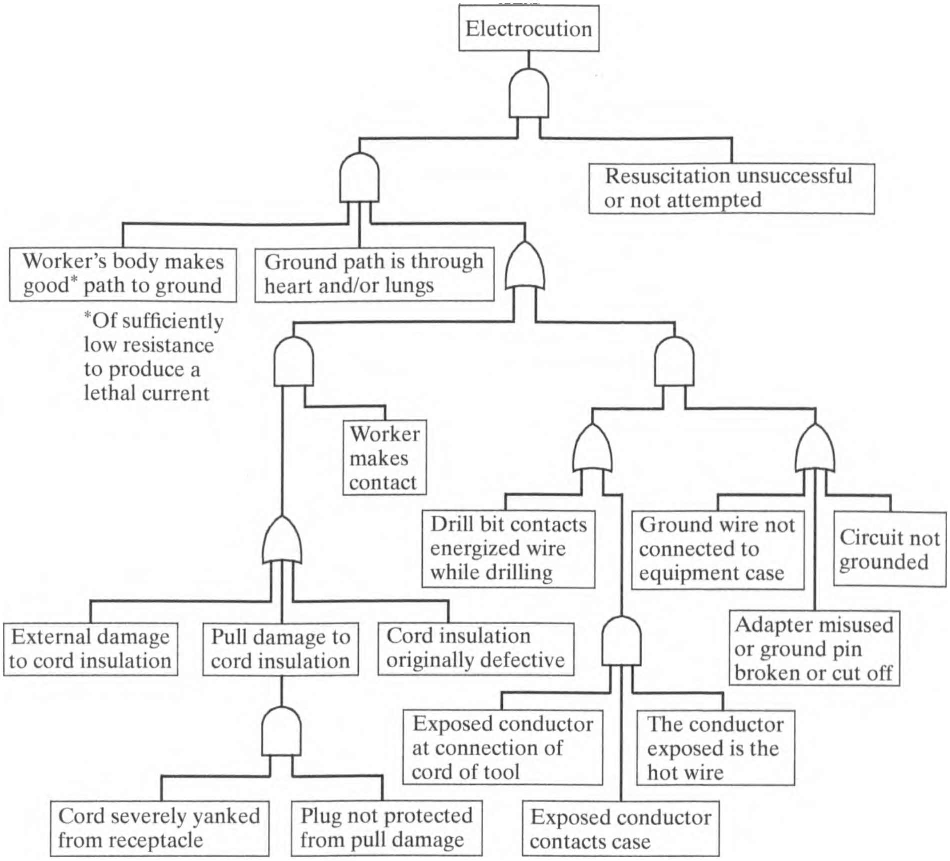

FIGURE 3.2

Fault-tree analysis of hazard origins in the electrocution of workers using portable electronic drills (not double insulated).

other undesirable result being studied. Figure 3.2 shows a sample fault-tree diagram of the network of causal relationships that can contribute to the electrocution of a worker using a portable electric drill.

The diagram in Figure 3.2 reveals the use of two symbols in coding causal relationships. Figure 3.3 deciphers this code. It is essential that the analyst be able to distinguish between the AND and the OR relationship for event conditions. All of the causal event conditions are required to be present to cause a result to occur when the conditions are connected by an AND gate. However, a single condition is sufficient to cause a result

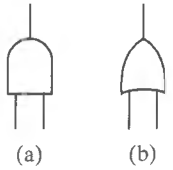

FIGURE 3.3

The logic codes for fault-tree diagrams are (a) AND-gate symbol; (b) OR-gate symbol.

to occur when conditions are connected by an OR gate. For example, oxygen, heat, and fuel are all required to produce fire, so they are connected by an AND gate, as shown in Figure 3.4. However, *either* an open flame or a static spark may be sufficient to produce ignition heat for a given substance, so these conditions are connected by an OR gate, as shown in Figure 3.5. Note that Figures 3.4 and 3.5 could be combined to start the buildup of a fault-tree branch.

One difficulty with fault-tree analysis is that it requires each condition to be stated in absolute "yes/no" or "go/no-go" language. The analysis breaks down if a condition as stated may or may not cause a specified result. When the analyst is confronted with a "maybe" situation, it usually means that the cause has not been sufficiently analyzed to determine what additional conditions are also necessary to effect the result. Therefore, the difficulty in dealing with a "maybe" situation forces the analyst to look more deeply into the fault relationships, so the "difficulty" may be a benefit after all.

Fault-tree analysis permits the analyst to compute quantitative measures of the probabilities of accident occurrence. The computation is tricky, however, and is at best only as good as the estimates of the probabilities of occurrence of the causal conditions. It seems intuitive that one should add the probabilities of events leading into an OR gate and multiply the probabilities of events leading to an AND gate. This intuition is wrong in both cases and is shown for the OR gate as follows: Suppose, in the example shown in Figure 3.5, that the probabilities of occurrence of the two event causes were as given in the following table:

Event cause	Probability of occurrence (%)
Open flame	50
Static spark	50

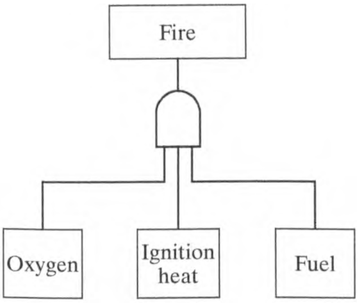

FIGURE 3.4

Example use of the AND gate in fault-tree diagrams.

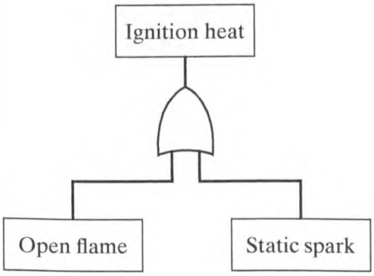

FIGURE 3.5

Sample use of the OR gate in fault-tree analysis.

To add these two probabilities would result in a 100% chance of reaching "ignition heat," an obviously erroneous result. A 50–50 chance of either of two possible causes is insufficient basis to find a 100% certainty of any resulting event. To make the logic even more convincing, the reader should rework the example using the following probabilities:

Event cause	Probability of occurrence (%)
Open flame	60
Static spark	70

Obviously, no result can have a probability of 130%! The correct probability computation is to subtract the "intersection," or probability that both independent causes would occur:

$$\begin{aligned} P[\text{ignition heat}] &= P[\text{open flame}] + P[\text{static spark}] \\ &\quad - P[\text{open flame}] \times P[\text{static spark}] \\ &= 0.6 + 0.7 - 0.6 \times 0.7 \\ &= 1.3 - 0.42 = 0.88 = 88\% \end{aligned}$$

For OR gates in which there are several event causes, the computation becomes very complex. Adding to the complexity is the question of whether the event causes are *independent*, that is, the occurrence of one event does not affect the likelihood of the occurrence of the other event cause(s). A special case of *dependent* events are events that are *mutually exclusive*, that is, the occurrence of one event *precludes* the occurrence of the other(s). The mutually exclusive condition simplifies the computation, but event causes in fault-tree diagrams are typically not mutually exclusive.

Fully resolving the problem of fault-tree computations would require a treatise on probability theory, which is beyond the scope of this book. Suffice it to say that fault-tree probability computations are more complex than most people think they are and therefore are usually done incorrectly.

Despite the computational problems associated with fault-tree computations, the fault-tree diagram itself is a useful analytical tool. The diagramming process itself forces the analyst to think about various event causes and their relationship to the overall problem. The completed diagram permits certain logical conclusions to be reached without computation. For instance, in Figure 3.2, the event "Worker makes contact" is key because, from the diagram it can be seen that the prevention of this event would preclude any of the five events to the lower left in the diagram from causing electrocution. Even more important is the event "Worker's body makes good path to ground." Prevention of this one single event is sufficient to prevent electrocution, according to the diagram. The reader can no doubt draw other interesting conclusions from Figure 3.2. These conclusions can result in a more sophisticated understanding of the hazard and in turn may lead to revisions to make the diagram more realistic. Such a developmental process leads to the overall goal of hazard avoidance.

Fishbone Diagrams

Similar in concept to the fault-tree diagram is the fishbone diagram credited to quality management pioneer Kaoru Ishikawa. In the fishbone diagram, the various causal factors are seen as branch bones along a fish spine, with the result being the central spine bone. As with fault-tree diagrams, the branch causes can be complex, resulting in a diagram that appears more like a tree on its side with branches connected to a central trunk. As with the fault-tree diagram, the primary benefit is in visualizing the causal relationships, not in calculating exact probabilities of end result occurrence.

Swiss Cheese Theory

The objective of eating a Swiss cheese sandwich is to eat the cheese, not the holes. This works pretty well, especially if several slices of cheese are stacked together so that the holes are not likely to line up. This may be OK for Swiss cheese sandwiches, but the analogy can be used to consider the consequences of holes in accident prevention measures. Figure 3.6 illustrates the systems safety concept of "Swiss cheese." When a serious accident is at stake, a strategy of depending on the holes not lining up at the same time is just not acceptable. The Swiss cheese theory is a popular concept of

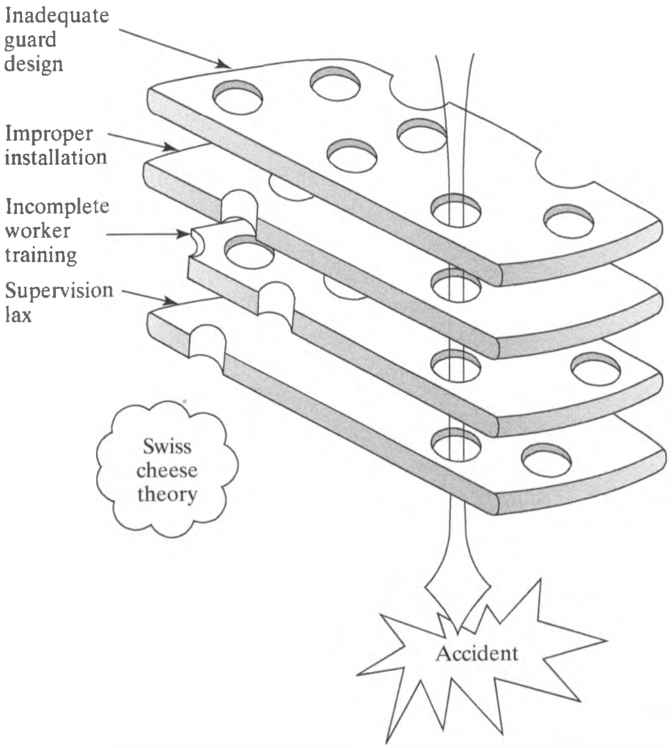

FIGURE 3.6

Swiss cheese theory. Accidents occur when protective measures are left to chance. The Swiss cheese holes may line up.

systems safety and is credited to Professor James Reason, a psychologist in Manchester, United Kingdom (Les Posen's Fear of Flying Weblog, 2004). Murphy's Law, in contrast, indicates that all of the holes will invariably line up!

Loss Incident Causation Models

Another related analysis model emphasizes the causes of *loss incidents*, whether or not the incident results in personal injury, as reported by Robert E. McClay (McClay, 1989). McClay's model attempts to take a universal perspective in which the entire causal system is examined, including primary causes—labeled *proximal* causes—and secondary causes—labeled *distal* causes. A proximal cause would be a direct hazard in the conventional sense of the word, for example, a missing guard on a punch press. By contrast, an example of a distal cause would include a management attitude or policy that is deficient in allocating resources and attention to the elimination of hazards. Distal causes are as important as proximal causes, because, although the effect of distal causes is less direct and immediate, distal causes create and shape proximal causes.

A critical point in the progression of the loss incident causation model is the *point of irreversibility*. McClay identifies this as the point at which the various interacting proximal causes will result in a loss incident. Despite the number and variety of proximal causes, only a few select cases will result in a sequence of events in which the point of irreversibility is reached. Once this point is reached, a loss incident is unavoidable. This is still not to say that an injury will occur. A loss incident can occur, and still no personnel might be exposed, or perhaps whatever exposure does occur is not injurious. Factors such as personnel exposure in the event of a loss incident affect the severity of the effects of the incident after the point of irreversibility has been exceeded. Such factors affecting the outcome can be either negative or positive, that is, they can be *aggravating factors*, which make the outcome more severe, or they can be *mitigating factors*, which make the outcome less severe.

Toxicology

Toxicology is the study of the nature and effects of poisons. Industrial toxicology is concerned especially with identifying what industrial materials or contaminants can harm workers and what should be done to control these materials. This is really a broad statement because virtually every material is harmful to living organisms if the exposure rate or quantity is great enough.

Many toxicological studies are performed on animals to provide a basis for conclusions about the hazards to humans. These animal studies are essential because most toxicological experiments would cause death or serious harm to human subjects. The disadvantage is that animal defenses to various toxic substances vary between species. The more the field of toxicology advances, however, the more various toxic materials can be classified and their effects predicted even before experiment. Rabbit–man, monkey–man, mouse–man, and guinea pig–man comparisons of species' defenses to various agents are becoming fairly well known.

A field that relates to both pharmacology and toxicology is *pharmacokinetics*. Bischoff and Lutz (Bischoff and Lutz, 1992) define pharmacokinetics as follows: "Pharmacokinetics is a description of the absorption, disposition, metabolism, and elimination of chemicals in the body, and is useful in both pharmacology and toxicology." It is important to the pharmacologist to understand how medical chemicals are handled within the body. In a similar way, it is important to the industrial toxicologist to understand how toxic chemicals are handled within the body.

Epidemiological Studies

Epidemiology is contrasted with toxicology in that epidemiology studies are strictly of people, not animals. The word obviously derives from the word *epidemic*, and in the literal sense, epidemiology is the study of epidemics. The epidemiological approach examines populations of people to associate various patterns of possible disease causes with the occurrence of the disease. It draws heavily on the analytical tools of mathematical statistics.

A classic epidemiological study was the association of the disease rubella (German measles) in pregnant women to birth defects in the infants born of those pregnancies. The study began with a curiosity observed by N. McAlister Gregg, an Australian ophthalmologist, in 1941. He observed eye cataracts among infants born of mothers who had had German measles during pregnancy in 1939 and 1940. The phenomenon might have gone unnoticed except for the Australian epidemic of rubella during the World War II buildup. Years of statistical epidemiological studies later confirmed a strong relationship between rubella during pregnancy and a wide variety of birth defects in infants born of those pregnancies.

Epidemics are usually thought of as attacking a general population at a specific time in a specific geographical area. Examples are the bubonic plague in Europe in the mid-fourteenth century and the rubella epidemic in Australia during 1939 to 1940. However, more subtle epidemics attack a specific subgroup of people who may be spread out over time and place. In other words, the victims of a particular epidemic may not live in one place or at one time, but instead have some other common characteristic, such as what they *do*. This aspect of epidemiology is what makes it important to occupational safety and health. Thus, lung fibrosis may not be a very common disease in any location or at any time. However, when the population of only those persons who have worked with asbestos is examined, it can be seen that, after a long latency period, lung fibrosis can be considered an epidemic. Epidemiological studies linking lung fibrosis to asbestos have led to the identification of a type of lung fibrosis known as *asbestosis*. Other epidemiological links are *brown lung* to textile workers, *black lung* to coal miners, and angiosarcoma to vinyl chloride workers. A recent epidemiological study is examined in Case Study 3.8.

CASE STUDY 3.8

EPIDEMIOLOGICAL STUDY

This study was performed in the early 1990s by researchers at Johns Hopkins University in an investigation funded by the IBM Corporation (Computer Chips and Miscarriages, 1992). The population studied was pregnant women who worked with diethylene glycol dimethyl ether and ethylene glycol monoethyl ether acetate—chemicals used in the making of computer chips. Only 30 women were studied in the target population, but the results were seen to be significant because of the high percentage of miscarriages that occurred in this group. Of the 30 women studied, 10 had miscarriages—a rate of 33.3%! This compares with a miscarriage rate of 15.6% among women not exposed to the chemicals.

From Case Study 3.8, it can be seen that an epidemiological study can be a powerful tool to linking a potential hazard to observed occupational diseases. It becomes an excellent preliminary step to in-depth studies that pinpoint the causal relationship that underlies the observed link.

Both epidemiology and toxicology are important elements in the analytical approach to avoiding hazards, but the safety and health manager does not typically perform such studies. The studies provide the basis for mandatory standards that are subsequently used in the enforcement approach. Safety and health managers may also use the results of such analytical studies to substantiate the psychological approach or as a justification for an engineering approach to a health problem.

Cost–Benefit Analysis

Chapter 1 set the record straight on the importance of hazard costs. Like it or not, people do make cost judgments on occupational safety and health—not just management, but workers, too. In the world of reality, funds do have limitations, and cost–benefit analyses must be used to compare capital investment alternatives. Safety and health managers, who feel that they can justify at any cost capital investment proposals that can be shown to have the possibility of preventing injuries and illnesses, can easily appear naïve. There is always more than one opportunity to improve safety and health, and cost–benefit analyses provide the basis for deciding which ones to undertake first.

The biggest difficulty with cost–benefit analysis is the estimation of the benefit side of the picture. Benefits to safety and health consist of hazard reduction, and to make the cost–benefit analysis computation, some quantitative assessment of hazard must be made. Such probabilities of injury or illness are very difficult to determine. Statistical data are being compiled at the state level, as discussed in Chapter 2. However, these data are still usually of insufficient detail to permit a quantitative determination of existing risk. In addition to this determination, an estimate of expected risk *after* the improvement must also be made, since it cannot be assumed in general that every safety and health improvement will completely eliminate hazards. Case Study 3.9 illustrates the method of cost–benefit analysis.

In Case Study 3.9, the reader will perceive the large degree of speculation in the estimates of hazard costs. Such speculation casts doubt on the entire analysis, but it is better to speculate and calculate than to completely ignore the cost–benefit tradeoff. This is an opportune point to lead into the next section of this chapter—hazards classification. There is a great deal to be gained from a subjective analysis of hazard costs, without resorting to overly sophisticated quantitative analysis, the credibility of which "hard" data may not support.

CASE STUDY 3.9

COST–BENEFIT ANALYSIS OF INSTALLING A PARTICULAR MACHINE GUARD

Cost	
Amortization of initial investment	
Initial cost	$4000
Expected useful life	8 years
Salvage value	0
Interest cost on invested capital	20%
Annual cost = $4000 × (20% interest factor for 8 years) = $4000 × 0.26061	$1042
Expected cost of annual maintenance (if any)	0
Expected annual cost due to reduction in production rate (if any)	$800
Total expected annual cost	**$1842**
Benefit	
Estimated tangible costs per injury of this type	$350
Estimated intangible costs per injury of this type	$2400
Total costs per injury	$2750
Average number of injuries per year on this machine due to this hazard	1.2
Expected number of injuries of this type after guarding	0.1
Expected reduction in injuries per year	1.1
(Expected benefit = $2750 × 1.1)	**$3025**

Since the total expected benefit of $3025 is more than the total expected cost of $1842, the conclusion is that it would be worthwhile to install this machine guard.

HAZARD-CLASSIFICATION SCALE

The absence of hard data to support quantitative cost–benefit analyses leaves a void of tools or benchmarks for use by the safety and health manager, safety committee, or another party on whom the decision responsibility for safety and health improvement may be thrust. Some sort of ranking or scale is needed to distinguish between serious hazards and minor ones so that rational decisions can be made to eliminate hazards on a worst-first basis.

OSHA does recognize four categories of hazards or standards violations as follows:

- Imminent danger
- Serious violations

- Nonserious violations
- De minimis violations

Chapter 4 explains these categories in more detail. However, the categories are rather loosely defined and are distinguished chiefly by the extent of the penalty authorized for each type. The imminent danger category qualifies OSHA to seek a U.S. District Court injunction to force the employer to remove the hazard or face a court-ordered shutdown of the operation. A month after the Imperial Sugar explosion of February 2007 in Port Wentworth, Georgia, OSHA cited imminent danger and inspected and shut down other Imperial plants until the hazards seen in the Port Wentworth plant were abated. The de minimis violations, by contrast, are merely technical violations that bear little relationship to safety or health; they typically do not carry a monetary penalty. However, the designations of which violations will be recognized as falling into which category of hazard is especially unclear.

It is perhaps impossible to define clear-cut categories in every instance, but much is to be gained by some type of subjective ranking of workplace hazards. The thesis of this book is that a scale of 1 to 10 should be attempted, crude as that scale might be. Until people start talking about degrees of hazards on such a quantitative scale, little progress can be made toward establishing an effective and orderly strategy for hazard elimination. On a 10-point scale, a “10” is characterized as the worst hazard imaginable, while a “1” is the least significant or mildest of hazards.

The 10-point scale is recommended because such a scale has become very popular in everyday speech. Facilitated by the media, especially television, the public has come to understand a statement such as “on a scale of 1 to 10, that item (tennis match, ski slope, kiss, etc.) was at least a 9.” The familiarity of this popular jargon can be employed to characterize workplace hazards.

Table 3.1 is a first attempt to describe subjectively each of 10 levels of hazards. The definitions address basically four types of hazards: fatalities, health hazards, industrial

Table 3.1 Category Descriptions for a 10-Point Scale for Workplace Hazards

1.	“Technical violations”; OSHA standards may be violated, but no real occupational health or safety hazard exists
2.	No real fatality hazard Health hazards minor or unverified Even minor injuries unlikely
3.	Fatality hazard not of real concern Health hazards have exceeded designated action levels *or* Sound exposure action levels exceeded (e.g., continuous exposure to sound in the range 85–90 dBA) *or* Minor injury risks exist, but major injury hazard is very unlikely
4.	Fatality hazard either remote or nonexistent Health hazards characterized by illnesses that are usually temporary; controls or personal protective equipment may not be required *or* Temporary hearing damage will result without controls or protection, and a few workers may incur partial permanent damage *or* Minor injuries likely, such as cuts and abrasions, but major injury risk is low

(*continued*)

Table 3.1 *(Continued)*

5. Fatality hazard either remote or not applicable
   Long-range health *may* be at risk; controls or personal protective equipment *advisable* or *required* by OSHA
   or
   Hearing damage may be permanent without controls or protection (e.g., continuous 8-hour exposure in the range of 95–100 dBA)
   Major injuries such as amputation not very likely
6. Fatality hazard unlikely
   Long-range health definitely at risk; controls or personal protective equipment *required* by OSHA
   or
   Hearing damage likely to be permanent without controls or protection (e.g., continuous 8-hour exposure in the range 100–105 dBA)
   or
   Major injury such as amputation not very likely, but definitely *could* occur
7. Fatality not very likely, but still a consideration
   or
   Serious long-range health hazards are proven; controls or personal protective equipment essential to prevent *serious* occupational illnesses
   or
   Hearing damage obviously would be *severe* and permanent without protection (e.g., continuous 8-hour exposure in excess of 105 dBA)
   or
   Major injury such as amputation could easily occur
8. Fatality possible; this operation has never produced a fatality, but a fatality easily could occur at any time
   or
   Severe long-range health hazards are *obvious*; controls or personal protective equipment essential to prevent *fatal* occupational illnesses
   or
   Major injury is likely; amputations or other major injuries already have occurred in this operation in the past
9. Fatality likely; similar conditions have produced fatalities in the past; conditions too risky for normal operation; rescue operations are undertaken for injured workers with rescuers using personal protective equipment
10. Fatality imminent; risks are grave; some employees earlier in the day have died or are dying; conditions are too risky even for daring rescue operations except perhaps with exotic rescue protection

noise hazards, and safety (injury) hazards. A clear-cut delineation is obviously difficult, and some readers no doubt will disagree with the wording of the definitions. Criticisms of the scale will reflect both the shortcomings of the definitions and the biases of the critics themselves. Acoustical experts, for instance, may want to place a high degree of emphasis on excessive noise hazards. Other specialists will want to emphasize other areas.

One critical test is met by the proposed scale. Within each hazard type, each successive level of the scale describes a progressively more severe hazard. Individual industries may devise more suitable definitions, but the idea is to start talking and thinking about hazards in terms of a 10-point scale.

One criterion omitted from the scale definitions is the cost of compliance, or the cost of correcting a given hazard. Cost is a completely different criterion and is almost independent of the level of hazard. That is, it can easily cost just as much or more to correct a Category 2 hazard as it does to correct a Category 9 hazard. Cost is an important criterion in the decision-making algorithm, but is omitted from the scale definitions to permit a clear ranking of hazard priority first. Once the hazards have been sorted out, costs of hazard correction can be estimated and capital allocated for such correction according to a rational capital investment policy.

Another missing criterion, perhaps conspicuously so, is any mention of OSHA legal definitions of *imminent danger, serious violation*, and so on. To place these legal designations into fixed positions in the hazard scale would undermine the objectivity of the classification. Many persons have a preconceived notion of what legal penalty should or should not be imposed for a given hazardous situation. This bias is found in OSHA officers as well as their industrial counterparts. For instance, if a plant safety and health manager happens to believe that a given situation is not serious enough to warrant a plant shutdown, he or she would tend to prohibit selection of any designation that would bear the legal OSHA designation "imminent danger." This is despite the fact that reason would place the Category 10 definition into the imminent danger category.

Three credible profiles of the OSHA legal classification superimposed on the proposed 10-point scale are displayed in Figure 3.7. Profile A has an industry flavor and represents the viewpoints of some business executives. Profile A cannot be considered an extreme position because thousands of American businesses are headed by persons who believe that no government official should have the right to step in and close their businesses with or without a court order, regardless of hazards. Therefore, some business executives do not recognize the legal category "imminent danger." Profile A does at least recognize the imminent danger category, although the profile is skewed to the right. Profile C shows a contrasting position, being skewed to the left. Some OSHA officers have demonstrated that their positions are very close to Profile C. Profile C likewise is not the ultimate in the left extreme because some people believe that any fatality or amputation hazard should be classified as serious regardless of the remoteness of the hazard. Profile B represents a middle-of-the-road position.

A final consideration in the classification of hazards would be the industry environment in which the hazard is portrayed. What seems hazardous to a structural steel worker working 100 feet above the ground on a narrow beam is in an entirely different category from what seems hazardous to an accountant. A similar comparison could be drawn between a coal miner and a computer analyst. It is only hoped that as a first step at least, coal miners should know what other coal miners mean when they talk about

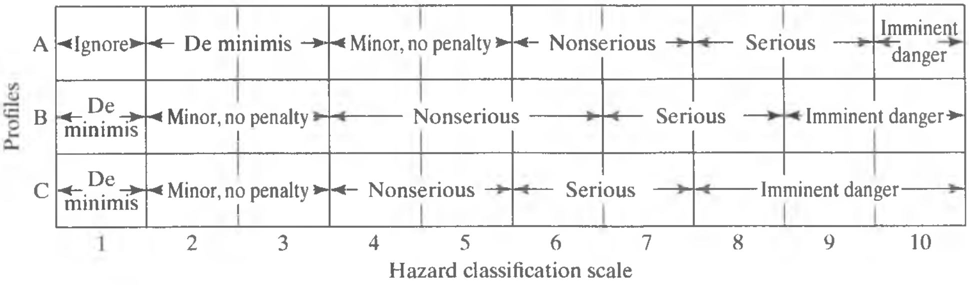

FIGURE 3.7

Three profiles of legal designations for hazards superimposed on the 10-point hazard classification scale.

Category 4 hazards. Similarly, accountants should be uniform in their conception of Category 9 hazards, for example.

Except for some very broad categories, such as "serious" and "nonserious," federal law has little to say about degree of hazard. No consistent criterion is available to safety and health managers, who must decide which problems must be tackled first. The 10-point scale recommended by this book for ranking safety and health hazards offers an opportunity to bring some order to this perplexing problem. The scale is a vehicle for encouraging all parties to focus on the degree of each hazard so that rational decisions can be made to correct those problems that are indeed significant.

It is more useful to rank hazards if some weight is placed on the likelihood of occurrence of the accident or loss incident. A fatality hazard is, of course, severe in terms of results, but if the likelihood of occurrence is extremely remote—as in air transport, for example—one cannot say that the hazard itself is severe. Risk analysis is the study that deals with this problem, and the U.S. Air Force has devised a "Risk-Assessment Code (RAC)" (AFI 91-202, 2016). The RAC system considers four levels of "severity" and four levels of "mishap probability," as shown in Table 3.2.

From Table 3.2, it can be seen that the Air Force RAC system results in a scale of 1 to 5 after considering both severity and mishap probability. The scale may be rather

Table 3.2 Risk-Assessment Codes

		Mishap probability			
		A	B	C	D
Mishap severity					
	I	1	1	2	4
	II	1	2	3	4
	III	2	3	4	5
	IV	4	4	5	5

Mishap severity

- **I.** Death, permanent total disability, or loss of facility or asset of $2,000,000 or more
- **II.** Permanent partial disability or major property damage of $500,000 up to $2,000,000
- **III.** Permanent partial disability or major property damage of $500,000 up to $2,000,000
- **IV.** Lost workday injury or compensable injury, or minor property damage $50,000 up to $500,000

Mishap probability

- **A.** Likely to occur immediately or within a short period of time
- **B.** Probably will occur in time
- **C.** Possibly will occur in time
- **D.** Unlikely to occur

RAC designations

1. "Critical/Imminent"
2. "Serious"
3. "Moderate"
4. "Minor"
5. "Negligible"

arbitrary, but it does make sense. Also, the RAC codes do create some order out of both severity and risk of occurrence in a single code. Case Study 3.10 will demonstrate the generation of a risk-assessment code for a given case of severity and mishap probability.

CASE STUDY 3.10

RISK-ASSESSMENT CODE

A defective condition has been noted in the instrument panel of a military aircraft. The panel often falsely indicates a fault in the oxygen system when in fact no fault exists. Pilots have sometimes ignored this fault indication because they have believed it to be a fault in the instrument itself, not a genuine fault in the oxygen system. The result, although highly unlikely, could be that a real oxygen hazard could go undetected, resulting in possible loss of the aircraft in flight and loss of life. The resulting assessment of the severity of this hazard is Category I and the assessment of mishap probability is Category D. From Table 3.2, the appropriate RAC to assign to this risk is Code 3.

A British standard titled "Standard Code of Practise for Safety of Machinery" 1988 sets up a classification system that assigns points for three hazard criteria—severity, potential for injury, and frequency of access—as follows:

Severity	**Description**	**Points**
Fatal/LTD	Loss of life, or long-term disability requiring hospitalization or treatment	6
Major	Permanent disability, loss of limb or sight, etc.	4
Serious	Loss of consciousness, burns, laceration, broken bones; anything requiring hospital treatment	3
Minor	Bruises, small cuts, light abrasions; anything that may require no more than local medical assistance	1
Potential for injury		
Certain		6
Probable		4
Possible		2
Unlikely		1
Frequency of access	**Description**	**Points**
Frequent	Many times per day	4
Occasional	Once or twice a day	2
Seldom	Weekly or less	1

The procedure is to add the total point score of the three categories to arrive at an overall hazard level or score to be used in decision making to alleviate the hazard (Standard Code of Practise for Safety of Machinery, 1988). The procedure is demonstrated in Case Study 3.11.

CASE STUDY 3.11

BRITISH STANDARD HAZARD CLASSIFICATION

A punch press is manually operated in a high-production operation at a standard production rate of 720 cycles per hour. In this setup, the operator feeds the press in every cycle. If ever the die closes with the operator's hand in the danger zone, an amputation is virtually a certainty. Obviously, every time the operator feeds the press, the hazard is present, but effective engineering controls using two-hand actuating devices makes the possibility of injury in a given cycle very remote. The problem is to examine severity, potential for injury, and frequency of access to obtain an overall assessment of the hazard level. By referring to the category definitions for each, the following assessment is made: The severity is "Major" (Code 4), because the hazard is an amputation; the potential for injury is very low because of the effective engineering control, "Unlikely" (Code 1); the frequency of access is thousands of cycles every day, so it is assigned a Code 4, "Frequent." The overall assessment is obtained by adding the three codes together to result in an overall assessment of $4 + 1 + 4 = 9$.

The concept of hazard classification can be carried a step further and applied to national decisions to invest billions in risk abatement. There is a growing concern for the need for a risk-assessment system that recognizes some level of risk associated with various national priorities for risk abatement. John C. Nemeth (Nemeth, 1991) writes, "I am convinced that well-founded, consistent risk assessment is the only way to proceed rationally. We need to get down to business and standardize." Jeremy Main (Main, 1991) raises the question of whether our nation is allocating funds for hazardous cleanup expenditures in a rational way. Main compares \$8 billion spent per year dealing with asbestos hazards, which are thought to cause zero to eight cancer deaths per year, with \$0.1 billion spent per year in dealing with radon hazards, which are believed to cause as many as 20,000 cancer deaths per year. Perhaps the nation's policy makers should use some sort of hazard classification scale to determine where the most money should be spent, rather than yielding to whatever thrust is politically popular at the time.

SUMMARY

The sophisticated safety and health manager is not content with one approach to dealing with workplace hazards. There is too much uncertainty to solve the enormous problems neatly with a simple approach, such as "awards for no lost-time accidents" or "fines for anyone who breaks the rules." These two approaches, together with all the others, have their place, but an integrated program using the strengths of all approaches has the greatest potential for success.

Although this chapter has emphasized the need for risk assessment, no foolproof procedure has been specified for assessing an exact quantitative level of risk. There will always be an element of judgment in weighing the risk and assigning a risk-assessment code, whether the system be the Air Force RAC method, the British Standard Code of Practise, or some other quantitative procedure. Benchmark levels can assist in the comparison of like risks, as was seen in the 10-point hazard-classification scale. Another helpful step in the assessment of risk is to seek the counsel of more than one opinion in attempts to determine quantitative levels. However, since no foolproof formula exists for assessing the risk, the safety and health manager should keep in mind the limitations of the method.

While becoming more sophisticated, safety and health managers may fall into the trap of becoming more enamored with their impressive-looking analyses, scientific formulas, and statistics, commonly known as *analysis paralysis*. Some of the best analyses may be subjective, not quantitative. The 10-point hazard-classification scale suggested in this chapter represents an opportunity for safety and health managers to talk and think about workplace hazards in terms of *degree*. Corporate top management has been looking for years for this breed of safety and health manager to emerge, who can discern between the really significant problems, the ordinary problems, and the trivial ones.

EXERCISES AND STUDY QUESTIONS

3.1 Name the four categories of seriousness of hazards as recognized by OSHA.

3.2 What is the OSHA designation for minor standards violations that bear little or no relationship to safety and health?

3.3 Consider the list of hazards that follows, and rank each on a scale of 1 to 10 (10 being the worst). Also, classify each into the four OSHA categories according to your opinion.

- **(a)** Ground plug (third prong) is cut off on a power cord for an office computer.
- **(b)** Ground plug is cut off on a power cord for a shop wet-vac vacuum cleaner.
- **(c)** An electric drill with faulty wiring causes an employee to receive a severe shock, after which he refuses to use it. Another employee scoffs at the hazard, claims that he is "too tough for 110 volts," and picks up the tool to continue the job.

3.4 A well-known safety rule is not to pull an electrical plug out of a wall socket by means of the cord. Have you broken this rule? Do you regularly do so? What is the reason for this rule? Do you think the rule is an effective one?

3.5 Do you believe that safety or health rules are "made to be broken"? Why or why not?

3.6 Name four basic approaches to hazard avoidance.

3.7 Recall your first supervisor in your first full-time job. Did he or she ever mention safety or health on the job? Was your supervisor's influence on your safety habits positive, negative, or neutral?

3.8 What is the Heinrich ratio?

3.9 What are the three lines of defense against health hazards?

3.10 What is the standard safety factor for crane hoists? for scaffolds?

3.11 Name three general fail-safe principles. Can you think of a real-world example of any such principles?

3.12 What does Murphy's law have to do with occupational safety and health?

3.13 What is the purpose of FMEA?

3.14 Construct a fault-tree diagram describing potential causes of fire in paint spray areas. Compare your analysis with others in the class.

3.15 Construct a fault-tree diagram that describes the ways in which a pair of dice can be thrown to "roll seven." Calculate the "risk" or chances of rolling seven.

3.16 Explain the difference between toxicology and epidemiology.

3.17 Alter the fault-tree diagram of Figure 3.2 to consider the possibility that the portable electric drill might be double insulated (i.e., sheathed in an approved plastic case to prevent electrical contact with the metal tool case).

3.18 In the universal loss incident causation model, what is the difference between proximal factors and distal factors? To which category does management policy belong?

3.19 Explain the concept of point of irreversibility. Does this point guarantee that a personal injury will occur? What are the roles of aggravating and mitigating factors?

3.20 Accident causes A, B, and C each has a probability of occurrence of about 1 in 1000, but the causes are mutually exclusive. Suppose that cause B does in fact occur in a given situation, what are the chances that cause A will occur in this situation?

3.21 Using a pair of dice for a simulation device, suppose that an outcome of 11 represents an industrial accident.

- **(a)** Draw a fault-tree diagram to illustrate the ways in which this accident could happen.
- **(b)** Calculate the probability that this accident will happen in a given throw of the dice.
- **(c)** Are the causes of this accident mutually exclusive?

3.22 The following are some causes of slips and falls:

- **(a)** Oil leaks from forklift trucks
- **(b)** Water or wax on floor during cleaning operations
- **(c)** Ice on walkways or loading docks during winter weather
- **(d)** Slippery heels on footwear

From the perspective of a total plant safety program, are these causes mutually exclusive? Why or why not? For a given single accident, are these causes mutually exclusive? Why or why not?

3.23 The following are three among many causes of injury to an operator of a punch press:

- **(a)** Barrier guard of adequate size but placed too high—worker can reach under the guard.
- **(b)** Barrier guard of adequate size but placed too low—worker can reach over the guard.
- **(c)** Openings in the barrier guard are too large—worker can reach through the guard.

Which of these causes are mutually exclusive?

3.24 A certain type of injury has tangible costs of $15,000 per occurrence and intangible costs estimated to be $250,000 per occurrence. Injury frequency is 0.01 per year, but would be reduced by half with the installation of a new engineering control system. What annual benefit would the new system provide?

3.25 A certain ventilation system would cost a firm approximately $60,000, which can be amortized over its useful life at a cost of $15,000 per year. Annual maintenance costs are expected to be $600 per year and monthly operating costs (utilities) $150 per month. The system is expected to facilitate production by reducing the amount of machine cleaning for an expected annual savings of $1200 per year. The primary benefit of the proposed ventilation system is expected to be the elimination of the need for respirators, which cost the company $4000 per year in equipment, maintenance, employee training, and respiratory system management. The ventilation system is expected to reduce short-term-illness complaints by an average of 6 per year and long-term illnesses by an average of 0.2 per year. Short-term illnesses result in a total cost of $600 per occurrence, including intangibles. Long-term illnesses are expected to result in a total cost of $30,000 per occurrence, including intangibles. Use a cost–benefit analysis to determine whether the ventilation system should be installed. What is the primary benefit of the ventilation system?

3.26 On a scale of 1 to 10 (10 being the worst), how would you rate each of the following hazards?

- **(a)** A 10-foot balcony does not have a guardrail. Workers regularly work close to the edge every day without fall protection.
- **(b)** Same as part (a), except that the working surface is outdoors and is very slippery in rainy weather.
- **(c)** No guardrail on a 10-foot balcony accessed only twice per year by a maintenance worker to service an air conditioner.
- **(d)** An unguarded flat rooftop accessed only by air conditioner maintenance personnel. The closest necessary approach to the edge of the roof is 25 feet.
- **(e)** Broken ladder rung (middle rung of a 12-foot ladder).
- **(f)** Overfilled waste receptacles in lunchroom.
- **(g)** A 2-ton hoist rope with dangerously frayed and broken wires in several strands.
- **(h)** Mushroomed head on a cold chisel.

3.27 What limits the region of sphere of control, and what factors belong to this region?

3.28 Under what circumstances is it incorrect to use the simple sum of causal event probabilities to calculate the probability of an event that results from either of two sufficient causal events?

3.29 Event A has probability of occurrence p_a, Event B has probability of occurrence p_b, and A and B are independent. Either A or B is sufficient cause for loss incident Event C to occur. Write a formula to calculate the probability of occurrence of loss incident Event C.

3.30 Event A has probability of occurrence 0.3, Event B has probability of occurrence 0.2, and A and B are independent. Either A or B is sufficient cause for loss incident Event C to occur. Calculate the probability of occurrence of loss incident Event C.

3.31 Study the OSHA standards to find examples of the application of each of the three fail-safe principles.

3.32 What engineering concept appears to have been misapplied in the Kansas City hotel skywalk disaster?

3.33 What is a "deadman control?" Describe an example not given in this book.

3.34 Describe an example of the use of "redundancy" in engineering design not given in this book.

3.35 Defensive driving is an example application of which of the three fail-safe principles?

3.36 Describe how FMEA can be a benefit to a preventive maintenance program.

3.37 It can be said that almost any substance is poison to humans. Explain how this can be true by citing an example of a seemingly harmless substance.

3.38 Explain the term "pharmacokinetics" and how it applies to occupational safety and health.

3.39 In what way is the field of epidemiology useful to occupational safety and health?

3.40 What persons or institutions perform toxicology and epidemiology studies and why? Would safety and health managers usually be expected to perform such studies?

3.41 Which do you think is a more serious hazard, radon or asbestos? Why?

3.42 What is a Poisson process? How is it related to "Murphy's Law"?

3.43 When a safety and health manager questions a process that has been practiced within the plant over many years, what engineering design principle is being considered?

3.44 Explain the distinction between guards and barriers in the application of engineering design principles.

3.45 What drawback should be avoided in applying the engineering design principle of "warning?"

3.46 Have you ever ignored a warning label on a machine? Why are warning labels sometimes ignored? What alternate solutions to problem hazards might be better than hazard warning labels?

3.47 Explain how the analytical approach to dealing with workplace hazards can be used to facilitate the other three approaches.

3.48 Of the four major approaches to hazard avoidance discussed in this chapter, which two of the four have been used to motivate motorcycle riders to wear helmets? In your opinion which of the two has been more effective?

3.49 Why does top management support alone fail to get the job done in using the psychological approach to hazard avoidance? What else is needed?

3.50 Identify 10 design principles or methods used to apply the engineering approach to reduce or eliminate hazards.

3.51 What primary benefit is shared by both fault-tree analysis and fishbone diagrams?

3.52 For what reason did OSHA shut down other Imperial Sugar refineries after the explosion of the Port Wentworth facility?

RESEARCH EXERCISES

3.53 From your own experience, from library research or from interviews with others, construct an actual case history of a fatal accident that was blamed on carelessness, but could have been prevented by a better engineering design.

3.54 Select a real hazard and gather information on the possible causes that could lead to an accident relevant to this hazard. Construct a fault-tree diagram to relate the causes to the loss event.

3.55 Search the Internet for details on the Kansas City hotel skywalk disaster.

3.56 Consider the following accident case history:

On July 4, 1980, three workers, ages 14, 16, and 17, were installing a sign at a bait shop along a state highway. They were using a truck-mounted extensible metal ladder to unload and position an upright steel support for the sign. Two of the workers were holding and guiding the steel support while the third stood on the flatbed truck operating the extensible-ladder controls. The metal ladder came into contact with a 13,200-volt overhead power line. The two workers guiding the steel support were standing on the ground and were subjected to immediate electrocution. The third worker attempted to break contact with the power line by operating the controls, but the controls had become useless, probably because the control wiring had become burned by the high-voltage contact. The worker then leaped from the truck and ran around to the front to try to drive the truck away to break contact. As he grasped for the door handle to the truck cab, he was still standing on the ground, which provided a path for the current through his body. The utility company had equipped the line with a "recloser" that normally would have broken the circuit under these conditions, but for a variety of reasons it failed to do so in this case. Therefore, the power remained on for a rather lengthy period. The high-voltage and burning current finally broke down the dielectric strength of the rubber tires and they blew out. This shifted the truck's position, and contact with the power line was broken, but not before one worker had been burned in half and another's legs were burned off; all three workers died. How could future accidents of this type be prevented? Compare the four basic approaches to hazard avoidance in preventing accidents of this type.

STANDARDS RESEARCH QUESTIONS

3.57 Use the OSHA website or the database on the Companion Website to search for OSHA General Industry standards that relate to training. Determine the percentage of citations that are classified as "serious."

3.58 Search the OSHA standards for the use of the word *engineering* in any of the General Industry standards.

3.59 From what you have learned in this chapter, compose a list of five words that you associate with the engineering approach to safety and health hazards. Do a search of the OSHA standards to determine whether any of these words appear in the General Industry standards.