24 Injuries

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Occupational injuries are caused by acute exposure in the workplace to physical agents such as mechanical energy, electricity, chemicals, and ionizing radiation, or from the sudden lack of essential agents, such as oxygen or heat. Examples of events that can lead to worker injury include motor vehicle crashes, assaults, falls, being caught in parts of machinery, being struck by tools or objects, and submersion. Resultant injuries include fractures, lacerations, abrasions, burns, amputations, poisonings, and damage to internal organs.

Occupational injuries are a serious public health problem. In 1996, more than 6,100 workers died from occupational injuries (1) and more than 6 million workers sustained nonfatal injuries, based on a survey of employers (2). This latter estimate is conservative because it relies on employer reporting and excludes important groups of workers, such as the self-employed, workers on small farms, and government employees. The annual societal cost of occupational injuries in the United States has been conservatively estimated at more than $145 billion (3).

CAUSES OF INJURIES

Although the immediate cause of injury is exposure to energy or deprivation from essential agents, injury events arise from a complex interaction of factors associated with materials and equipment used in work processes, the work environment, and the worker. These factors include physical hazards in the workplace or setting, hazards and safety features of machinery and tools, the development and implementation of safe work practices, the organization of work, the design of workplaces, the safety culture of the employer, availability and use of personal protective equipment (PPE), demographic characteristics of workers, experience and knowledge of workers, and economic and other social factors.

The case described in Box 24-1 illustrates how the occurrence of occupational injury events can be influenced by a variety of factors and circumstances. Some of the contributory factors are clear, others are surmised. The victim did not have experience doing this type of work, and may not have fully recognized all the fall hazards associated with the job, or the importance that fall protection be used. Social and economic factors may have contributed to the crew being asked and agreeing to do work they had never done before—for example, the need for the income from the job and their desire to be seen as employees who would do what was asked of them. A number of factors may have accounted for the absence of a comprehensive safety and training program, including the employer's perceptions that workers know how to conduct work safely and do

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Box 24-1. Laborer Dies After 41-Foot Fall from Roof under Construction

A 22-year-old male laborer worked as part of a four-man construction crew that normally performed floor, truss, and deck work. On the day of the incident, the crew was asked by their supervisor to roof a building because the regular roofing crew had been sent to another job. No one from the crew had ever done roofing work before, nor were they provided with fall protection equipment or any training in the recognition and avoidance of fall hazards. At approximately 7:00 a.m., the crew began installing sheets of plywood on roof trusses of a steep, pitched roof of an apartment building. Each member of the crew was working on a separate area of the roof carrying, laying, and nailing sheets of plywood to the trusses. The employer did not have an on-site safety program specifying hazards routinely faced by workers, such as hazards faced during roofing, or safety practices mandated by the employer to ensure work was done safely. Late in the afternoon, the victim fell 41 feet to the ground below from an unprotected roof edge. Emergency medical services arrived shortly after the incident, and pronounced the victim dead at the scene. The coroner listed the cause of death as blunt trauma injury to the head and chest.

National Institute for Occupational Safety and Health, Division of Safety Research. Fatality assessment and control evaluation (FACE) report 98-17 Morgantown, WV: National Institute for Occupational Safety and Health, Division of Safety Research, 1998.

not need guidance or training, employer and worker perceptions that fall protection decreases productivity, costs to hire safety and health expertise if not available with current staff, and costs associated with providing safety equipment and PPE. The fact that the victim did not speak English would have been a barrier to his taking part in weekly safety training meetings, held in English, by the general contractor for subcontractor workers.

This case illustrates that injury events can arise from a complex array of factors. Not all factors carry the same weight in contributing to injury events. In addition, the responsibilities for a safe work environment and safe work practices are not borne equally by all involved parties. The greatest responsibilities are borne by employers, who are responsible for providing a safe work environment, including the identification of potential safety hazards as well as the implementation of hazard controls and safe work practices and procedures to keep workers safe. Workers are responsible for following established procedures and for reporting safety hazards to employers.

EPIDEMIOLOGY OF INJURIES

Occupational injuries are not random events. They cluster or are associated with specific types of workplaces and jobs, workplace exposures, and worker characteristics. Violence in the workplace is one type of exposure contributing to occupational injuries (see Box 24-2). Because occupational injuries are not random, they can be anticipated and steps can be taken to prevent them.

Epidemiologic data allow those involved in injury prevention efforts to target groups and settings with high numbers or rates of occupational injuries, and to anticipate and take steps to prevent injury in specific workplaces or settings. Epidemiologic data on fatal and nonfatal occupational injuries differ and thus are addressed separately. Both categories of injuries require attention—fatal injuries, because they represent the most severe consequence of occupational injury and are devastating to families, communities, and workplaces; and nonfatal injuries, because of the sheer volume and aggregate costs to workers, families, employers, and society.

Fatal Injuries

The distribution and risks for fatal occupational injury differ by demographic characteristics of workers. Men account for more than 90% of occupational fatalities, and have fatality rates approximately 10 times higher

Box 24-2. Violence in the Workplace

The role of violence as a cause of work-related injury and death had been largely overlooked until the early 1990s, when the National Institute for Occupational Safety and Health (NIOSH) reported findings from its National Traumatic Occupational Fatality Surveillance System (NTOF).

Reviewing death certificate data for the 1980s, NIOSH found that approximately one in eight work-related fatalities in the United States is a homicide. The high prevalence of work-related homicides has continued into the 1990s. Among women, homicide is the largest single cause of death in the workplace, accounting for almost half of these deaths. Victims of occupational homicide are young (primarily 25 to 44 years of age). Although 73% are white, the rate of occupational homicide among African-Americans and other minority workers is more than twice that for whites.

Because of the availability of death certificates, the discovery of the importance of violence was primarily based on the surveillance of occupational fatalities. However, these data probably *underestimate* occupational violence. The problem is clearly more widespread when nonfatal effects of violence, ranging from injuries due to violent acts to sexual harassment on the job, are considered. Approximately 1 million workers are physically attacked at work in the United States each year. Data from the United Kingdom indicate that one in eight health care workers suffers a physical attack each year. Studies in the United States suggest that those responsible for violent events are most commonly patients receiving health care, customers, or strangers, with coworkers, relatives, and intimates accounting for fewer cases. The typical victim of occupational homicide is a regular worker employed in a work setting that allows continued exposure to hazards of crime and violence. Retail trade and service workers are those most frequently killed by violent acts at work; these workers accounted for 55% of occupational homicides in the 1980s and early 1990s. In this context, some of the most hazardous workplaces were taxicabs, liquor stores, gas stations, detective/protective services, and justice/public order establishments; some workers with the most hazardous occupations were taxicab drivers (with a risk of occupational homicide greater than 30 times the average), law enforcement officers, gas station workers, security guards, stock handlers/baggers, store owners/managers, sales clerks, and bartenders.

The circumstances of these fatalities indicate robbery as a primary motive, with some being caused by disgruntled workers and clients. NIOSH has summarized the major risk factors known to increase probability for occupational homicide: (a) exchange of money with the public, (b) working alone or in small numbers (Fig. 24-4), (c) working late-night or early-morning hours, (d) working in high-crime areas, (e) guarding valuable property or possessions, and (f) working in community settings, as taxicab drivers and police do.[1]

NIOSH has recommended preventive measures that can be quickly introduced to reduce the risk of occupational homicides, especially in high-risk establishments and occupations:

- Make high-risk areas visible to more people and install good external lighting.
- To minimize cash on hand, use drop safes, carry small amounts of cash, and post signs stating that limited cash is on hand.
- Install silent alarms and surveillance cameras.
- Increase the number of staff on duty and have police check on workers routinely.
- Provide training in conflict resolution and nonviolent response as well as the importance of avoiding resistance during a robbery.
- Provide bullet-proof barriers or enclosures.
- Close establishments during high-risk hours (late at night and early in the morning).

[1]National Institute for Occupational Safety and Health. Current Intelligence Bulletin 57: violence in the workplace. DHHS (NIOSH) publication no. 96-100. Cincinnati, OH: U.S. Department of Health and Human Services (DHHS), Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health, 1996.

than those for women. Approximately 80% of occupational fatal injuries are among white workers (including Hispanic workers), 10% among black workers, and 3% among Asian or Pacific Islander workers (1,4). Black workers have slightly higher fatality rates than white workers (4). One analysis suggested that most, but not all, of the difference in fatality rates between black and white men could be attributed to the types of jobs held by each (5). Differences in employment patterns have also been suggested as the reason for the sex disparity. Sixty-eight percent of fatal occupational injuries occur to workers between 25 and 54 years of age, with approximately 10% of the fatalities among workers younger than 25 years of age and 22% of the fatalities among workers 55 years of age and older. Rates of fatal occupational injury begin to increase at approximately 45 years of age, with the highest rates among workers 65 years of age and older (1,4). Decreased ability to survive injuries may account for some of the increased fatality rates among older workers.

Eighty percent of occupational injury deaths are among wage and salary workers; the remainder are among the self-employed, who have fatality rates approximately 2.5 times greater than wage and salary employees. The types of jobs held by the self-employed explain some of this difference (1). For example, higher proportions of the self-employed work in the agriculture and construction industries (two industries with the highest risk of fatal injury) than wage and salary workers.

Transportation-related events account for many occupational injury deaths each year: 42% of the 6,112 occupational injury deaths in the United States in 1996. These events involve motor vehicles and mobile equipment (e.g., tractors and forklifts), occur on and off the highway, and include pedestrians or bystanders as well as operators or drivers. Assaults and violent acts accounted for 19% of fatalities in 1996, with most of these events involving homicides, and some involving suicides and animal attacks. Contact with objects or equipment accounted for 16% of the fatalities, including being struck by falling objects (e.g., materials falling from cranes and trees falling down while being cut), being caught in running equipment or machinery, and being caught in or crushed by collapsing materials (e.g., in trench cave-ins or collapsing buildings). Falls, mostly to a lower level, accounted for 11% of fatalities. Exposure to harmful substances or environments (e.g., electric current, temperature extremes, hazardous substances, and oxygen deficiency) accounted for 9% of fatalities, with more than half of these being electrocutions. Fires and explosions accounted for 3% of the fatalities (1). There are some variations by demographic characteristics; for example, homicide typically accounts for higher proportions of deaths, and is frequently the leading cause of death for women, minorities, and the self-employed (1,4).

There is tremendous variability in the incidence of occupational injury deaths by industry division (Table 24-1), and among specific industries within industry divisions. The occupational injury fatality rate averaged across all industries in the United States in 1996 was 4.8 per 100,000 workers (1). There are dozens of specific industries with injury rates far in excess of the average for all indus-

TABLE 24-1. *Number and rate of fatal occupational injuries by industry division, 1996*

Industry division	No. of fatalities	Fatality rate[a]
Mining	152	26.8
Agriculture/forestry/fishing	798	22.2
Construction	1,039	13.9
Transportation/public utilities	947	13.1
Wholesale trade	267	5.4
Manufacturing	715	3.5
Retail trade	672	3.1
Services	767	2.2
Finance/insurance/real estate	114	1.5
Total	6,112	4.8

[a] Rate per 100,000 workers.

From Bureau of Labor Statistics. Fatal workplace injuries in 1996: a collection of data and analysis. Report 922. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, 1998.

tries—information on these industries can be accessed through routine and summary publications of occupational injury fatality data (1,6). Some of these high-risk industries are in industry divisions with relatively low rates of fatal injury—specifically, manufacturing, wholesale trade, services, and retail trade.

There is also considerable variability in the incidence and patterns of injury death by occupation. Table 24-2 provides information on the incidence and patterns of fatal injury for select detailed occupations. In some occupations, there is a predominant type of injury event, such as aircraft crashes among military occupations; in other occupations, such as those in farming, a variety of events contribute to injury death. Not included in Table 24-2 is information on several specific occupations with fewer numbers of deaths each year, but very high annual fatality rates, such as fishers (178.4 deaths per 100,000 workers) and structural metal workers (85.2 deaths per 100,000 workers) (1,6).

Nonfatal Injuries

Although not as dramatic as for fatal injuries, differences are also seen across demographic categories for nonfatal injuries. Men account for approximately 70% of nonfatal work-related injuries, and, based on data from emergency department visits, have rates from 1.6 to 1.8 times higher than those for women

TABLE 24-2. *Fatality rate and most frequent events leading to occupational injury death for select occupations, 1996*

Occupation	No. of deaths	Rate[a]	Most frequent events
Timber cutting and logging	118	157.3	Contact with objects and equipment (mostly struck by)—78% Transportation—14%
Airplane pilots and navigators	100	87.7	Transportation (all aircraft)—100%
Construction laborers	291	35.7	Transportation—31% Contact with objects/equipment—30% Falls—22% Exposure to harmful substances/environment—13%
Truck drivers	785	26.0	Transportation—79%
Farming occupations	589	24.8	Transportation—43% Contact with objects/equipment—26% Assaults and violent acts—10% Falls—10% Exposure to harmful substances/environment—10%
Laborers, except construction	213	15.9	Transportation—30% Contact with objects/equipment—30% Falls—13% Assaults and violent acts—12% Exposure to harmful substances/environment—11%
Electricians	98	12.8	Exposure to harmful substances/environment (mostly electrocutions)—51% Falls—18% Transportation—12% Contact with objects and equipment—10%
Police and detectives	114	11.9	Assaults and violent acts (mostly homicides)—52% Transportation—42%
Military	123	9.5	Transportation (mostly aircraft)—79%
Sales, supervisors and proprietors	225	5.0	Assaults and violent acts (mostly homicides)—70% Transportation—23%
Cashiers	94	3.3	Assaults and violent acts (mostly homicide)—92%

[a] Rate per 100,000 workers.

From Bureau of Labor Statistics. Fatal workplace injuries in 1996: a collection of data and analysis. Report 922. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, 1998.

TABLE 24-3. *Number and rate of nonfatal occupational injuries by industry division, 1996*

Industry division	No. of injuries[a]	Injury rate[b]
Manufacturing	1,952.9	10.6
Construction	483.8	9.9
Transportation/public utilities	514.4	8.7
Agriculture/forestry/fishing	113.0	8.7
Retail trade	1,117.5	6.9
Wholesale trade	412.9	6.6
Services	1,466.8	6.0
Mining	33.3	5.4
Finance/insurance/real estate	144.3	2.4
Total	6,238.9	7.4

[a] Number × 1,000.
[b] Rate per 100 full-time workers.
From Bureau of Labor Statistics. Workplace injuries and illnesses in 1996. Bulletin 97-453. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, 1997.

(7,8). Data from the annual survey of employers conducted by the Bureau of Labor Statistics (BLS) suggest that 53% of injuries and illnesses with lost workdays are among white, non-Hispanic workers, with non-Hispanic blacks and Hispanic workers each accounting for approximately 9% of lost workday cases (9). An analysis of emergency department data that did not separate out Hispanic ethnicity found that black workers had injury rates, approximately 1.3 times higher than white workers (8). Workers 25 to 54 years of age account for more than 73% of nonfatal injuries, those younger than 25 years of age account for approximately 16%, and those older than 54 years of age approximately 8% (9). Based on emergency department data, workers 18 to

TABLE 24-4. *Incidence and most frequent events of nonfatal occupational injury and illnesses requiring days away from work for select occupations, 1995*

Occupation	Estimated no. of injuries	Most frequent events
Truck drivers	151,338	Overexertion (mostly lifting)—29% Contact with objects/equipment (mostly struck by)—20% Transportation—12% Fall to same level—10%
Laborers, except construction	115,545	Contact with objects/equipment (mostly struck by)—34% Overexertion (mostly lifting)—31%
Nursing aides, orderlies, and attendants	100,596	Overexertion (mostly lifting)—59% Fall to same level—10%
Assemblers	55,537	Contact with objects/equipment (mostly struck by)—34% Overexertion (mostly lifting)—27% Repetitive motion—15%
Janitors and cleaners	52,582	Overexertion (mostly lifting)—30% Contact with objects/equipment (mostly struck by)—25% Fall to same level—14%
Construction laborers	43,496	Contact with objects/equipment (mostly struck by)—37% Overexertion (mostly lifting)—22% Fall to lower level—11%
Cooks	35,440	Contact with objects/equipment (mostly struck by)—30% Exposure to harmful substances—21% Overexertion (mostly lifting)—19% Fall to same level—18%
Carpenters	35,044	Contact with objects/equipment (most struck by)—38% Overexertion (mostly lifting)—23% Fall to lower level—14%
Stock handlers and baggers	34,711	Overexertion (mostly lifting)—36% Contact with objects/equipment (mostly struck by)—29%
Cashiers	30,177	Overexertion (mostly lifting)—28% Contact with objects/equipment (mostly struck by)—29% Fall to same level—20%

From Bureau of Labor Statistics. Occupational injuries and illnesses: counts, rates, and characteristics, 1995. Bulletin 2493. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, 1998.

19 years of age have the highest rates of injury, with injury rates decreasing with increasing age (7).

Information from the BLS annual survey of employers on employee tenure are available only for lost workday cases, and injuries are not separated from illnesses in published data (illnesses represent only approximately 7% of the cases). Thirteen percent of all cases occurred among employees with less than 3 months of service with the employer, 18% among employees with 3 to 11 months of service, 31% with 1 to 5 years of service, and 27% with more than 5 years of service with their employer (9).

The magnitude and risk of nonfatal injuries by industry division vary substantially from those for injury deaths (Table 24-3). The occupational injury rate averaged across all industries in 1996 was 7.4 per 100 workers. A substantial number of specific industries have injury rates far in excess of the average rate. Most are within the manufacturing industry division, with many in the lumber and wood products industries, primary metal industries, and the manufacture of transportation equipment.

Table 24-4 provides information on the estimated incidence (numbers, not rates) and patterns of nonfatal injury for select specific occupations (10). Many nonfatal injury events are common across a variety of occupations, with fewer examples of differences in occupation-specific injury event patterns. Injury patterns among occupations are important for focusing prevention efforts.

CLINICAL PRESENTATION AND COURSE OF INJURIES

Data from the 1998 National Health Interview Survey indicate that 34% of workers with occupational injuries are treated in emergency departments. The remainder are treated on-site, at private physicians' offices or clinics, or in other medical treatment facilities. Table 24-5 provides information on diagnoses and anatomic sites of occupational injuries treated in emergency departments in the United States in 1996. Sprains and strains accounted for 27% of the injuries, followed by lacerations (22%), and contusions/abrasions/hematomas (20%). Thirty percent of injuries were to the hand or finger (7). Among the 1996 work-related emergency department visits, wound care was provided to 34% of patients, extremity radiographs were ordered or provided to 30% of patients, and orthopedic care was provided to 21% of patients. Approximately 1.5% of injuries resulted in hospital admission (8).

Additional information on the course of

TABLE 24-5. *Occupational injuries treated in emergency department by diagnosis and anatomic site, 1996*

		Part of body affected					
Diagnosis	Estimated no.	Trunk, back, groin	Leg, knee, ankle	Arm, wrist, shoulder	Head, face, neck	Hand/ finger	Other
Sprain or strain	885,000	44%	22%	20%	6%	4%	3%
Laceration	731,000	<1%	6%	10%	15%	68%	1%
Contusion, abrasion, or hematoma	660,000	14%	17%	15%	21%	21%	12%
Dislocation or fracture	220,000	11%	15%	22%	4%	34%	15%
Burn	132,000	5%	8%	18%	38%	26%	6%
Other	674,000	10%	5%	10%	29%	29%	18%
Total	3,302,000	18%	13%	15%	17%	30%	8%

From National Institute for Occupational Safety and Health. Surveillance for nonfatal occupational injuries treated in hospital emergency department. *Morb. Mortal Wkly Rep* 1998;47:302–306.

injuries is available from the BLS annual survey of employers (9). Of the estimated 1.9 million injuries and illnesses with lost workdays in 1996, the median days away from work was five. Median days away from work were highest for amputations (20 days) and fractures (17 days). With respect to fatally injured workers, in 1996, 84% died the day they were injured; 97% died within 30 days (1).

PREVENTION OF INJURIES

Hierarchical Approach to Occupational Injury Control

Over the years, a number of models for occupational injury control have evolved. Many of these models categorize worker protection strategies based on a hierarchical approach, such as the five-tier model presented in Table 24-6. Other variations of this hierarchical approach have been published (11). Haddon proposed 10 basic strategies for injury prevention that have a number of similarities to the hierarchical approach, such as hazard elimination, hazard reduction, and using barriers for protection (12). Haddon also introduced the concept that injury causation was a chain of multifactorial events, each of which provided opportunities for intervention. Linn and Amendola (13) suggested an approach that combines the public health model with safety engineering analysis for injury prevention. The disciplines of epidemiology, safety engineering, biomechanics, ergonomics, psychology, safety management, and others form a multidisciplinary approach that is useful for identifying injury risk factors and developing control strategies (see Chapters 5, 6, 8, 9, 21, and 26).

TABLE 24-6. *Safety hierarchy*

Priority rank	Safety action
1	Eliminate hazard or risk
2	Apply safeguarding technology
3	Use warning signs
4	Train and instruct
5	Use personal protective equipment

Adapted from Barnett RL, Brickman DB. Safety hierarchy. Journal of Safety Research 1986;17:49–55.

Primarily, the hierarchical approach focuses on eliminating a hazard through design; using safeguards that eliminate or minimize worker exposure to a hazard; providing worker training in safe work practices and procedures; and using PPE to prevent or minimize worker exposure to hazards, or to reduce the severity of an injury if one occurs. In general, there are three main categories of control strategies: engineering control, administrative control, and the use of PPE.

Control Strategies

The optimal injury control strategy should be to eliminate a hazard completely. Many times, hazard elimination can be accomplished through equipment design. Consider the example illustrated in Box 24-3. Although a number of factors contributed to this fatal event, one of the National Institute for Occupational Safety and Health recommendations suggested that equipment and tool manufacturers design a unique coupling system to prevent the use of unsuitable hydraulic hoses on booms, aerial buckets, or aerial bucket attachments. In this situation, the unique design of the hose coupling mechanism could eliminate the hazard of metal-reinforced hoses on bucket truck booms, allowing only the appropriate type of hydraulic hose to be installed.

Because hazard elimination is not always possible, other control strategies in the hierarchy must be implemented to achieve worker protection. If a hazard cannot be eliminated completely, then the next control level should be to eliminate or minimize worker exposure through protective safeguarding technologies (commonly referred to as *engineering controls*). Effective engineering controls are designed into equipment, workstations, and work systems to provide protection without direct worker involvement—that is, passive control. Typically, engineering controls do not eliminate the hazard *per se*; rather, they prevent or

Box 24-3. Electrical Lineman Dies after Falling 35 Feet to the Ground from a Burning Aerial Bucket

A 37-year-old electrical lineman was sagging (adjusting slack in) the center phase of a three-phase, 12,400-volt, energized power line. A metal-reinforced rubber hydraulic hose was attached to an impact wrench the lineman was using. When the hose simultaneously contacted two phases of the power line, the heat generated by the electric current in the metal reinforcement caused the hose to melt and rupture. When the hydraulic fluid from the ruptured hose contacted the power line, the fluid ignited and the aerial bucket became engulfed in flames. The lineman attempted to jump to an earthen bank approximately 15 feet from the side of the bucket, but caught his foot on the bucket lip and fell 35 feet to the ground. A field mechanic had installed the metal-reinforced hose 5 months before the fatal incident. During later interviews, the mechanic stated that he knew he was installing the wrong type of hose but did not understand the hazards involved.

National Institute for Occupational Safety and Health. Request for assistance in preventing injuries and deaths from metal-reinforced hydraulic hoses. DHHS (NIOSH) publication no. 93-105. Cincinnati, OH: U.S. Department of Health and Human Services (DHHS), Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health, 1993.

minimize worker exposure to a hazard, as long as the control is in place and functions properly. Experience has shown that effective engineering controls must be well designed so as not to interfere adversely with the work process and introduce additional hazards.

Administrative controls also seek to eliminate or minimize worker exposure to hazards, but require behavioral actions by workers to be most effective. Administrative controls are usually defined as management-directed work practices or procedures that, when implemented consistently, reduce the risk of injury. Administrative controls are sometimes referred to as *active controls* because they require worker involvement to be effective.

Personal protective equipment is usually viewed as the last control option in the hierarchy. PPE consists of devices used to protect workers by reducing the risk that exposure to a hazard will injure the worker, or reducing the severity of an injury if one does occur. Although the hazard still exists, the potential for worker injury is mitigated through the PPE.

A comprehensive approach to worker injury prevention efforts inevitably includes all tiers of a control hierarchy to achieve maximum worker protection. The following sections provide some examples of each type of control.

Engineering Controls

Many types of industrial equipment require power transmission units that include belts, pulleys, gears, shafts, and other mechanisms necessary for the equipment to function. Workers can be exposed to serious, or even fatal, injury hazards if they come into contact with these rotating or moving components. A fixed barrier guard that completely encloses the power transmission unit is an engineering control that protects workers from these types of hazards. As long as the barrier guard remains in place, the worker is protected from injury. Another engineering control is an optical sensor (also called a *light curtain*) used to protect the point of operation (area where the machine operation takes place) on a mechanical power press (Fig. 24-1). In this example, the sensor is integrated into the press control mechanism so that if any part of the worker's body breaks the plane of light in front of the hazardous point of operation, either the down-

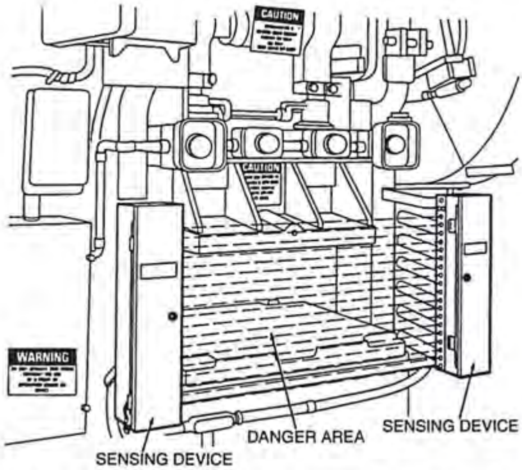

FIG. 24-1. Photoelectric (optical) sensor installed on a mechanical power press to protect the point of operation. (From Occupational Safety and Health Administration. Concepts and techniques of machine safeguarding. OSHA 3067. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, 1980.)

ward motion of the press ram cannot be initiated or it is automatically disengaged if motion has begun.

Many engineering controls are *interlocked* to ensure that they cannot be removed without disabling the machine or equipment. An

FIG. 24-2. Example of poor housekeeping on a construction site. Loose bricks, lumber, and other debris create a potential tripping hazard for workers.

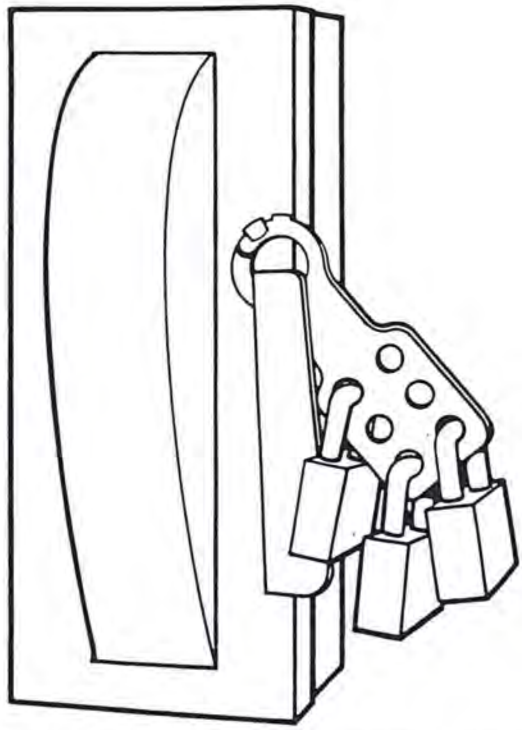

FIG. 24-3. Lock-out hasp on an electrical control panel provides a method for applying a lock (lock-out) to the panel during maintenance or repair to ensure that the equipment is not energized until the work has been completed. The control panel should also be tagged (tag-out) with a label indicating that work is being performed. Workers should be provided with individually keyed locks, and only the worker who applied the lock should remove it. (From Occupational Safety and Health Administration. Concepts and techniques of machine safeguarding. OSHA 3067. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, 1980.)

interlock is a device that is integrated into the control mechanism of a machine or work process to prevent the work cycle from being initiated until the interlock (usually, an electrical or mechanical control) is closed, signaling the equipment that the work cycle can be initiated. Interlocks need to be designed so that they are not easily bypassed or defeated.

Although engineering controls should be viewed as a primary tier of prevention, it is not always possible to develop such controls

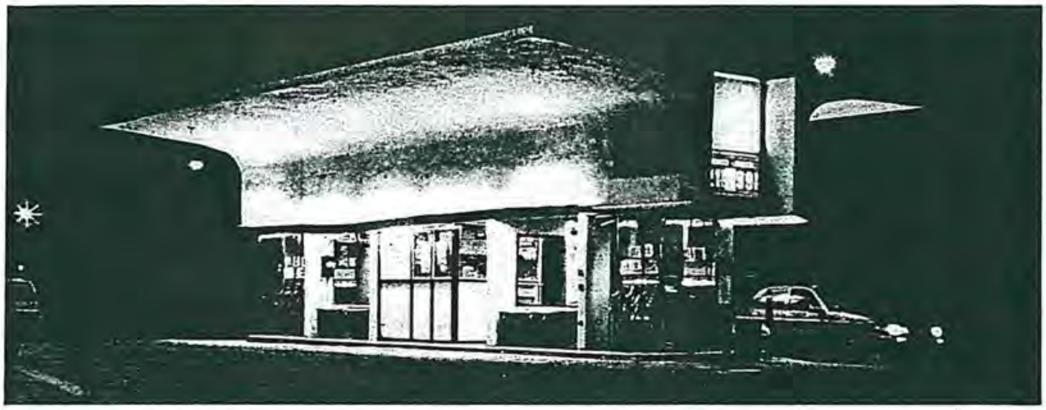

FIG. 24-4. Violent injuries are particularly a problem for workers employed in isolated work settings, such as this gas station. (Photograph by Marvin Lewiton.)

for all potentially hazardous work situations. Thus, administrative controls are the next tier for reducing or minimizing worker exposure to hazards.

Administrative Controls

An administrative control in the form of good housekeeping procedures requires that spills or debris be cleaned up to reduce the potential for a slip, trip, or fall injury. When spills or debris are cleaned up quickly, the potential hazard of a slippery work surface or tripping hazard is removed or minimized (Fig. 24-2).

The implementation of a hazardous energy control policy during maintenance activities is an administrative control in the form of safe work practices and procedures to prevent worker injuries due to inadvertent energization of equipment. Lock-out/tag-out procedures are important components of a hazardous energy control policy (Fig. 24-3). However, to be effective, the procedures must be written and consistently implemented, and workers trained in their use (14). Other examples of administrative controls are policies in retail establishments that increase visibility of cash exchange areas (through limited use of displays on storefronts) and minimize the amount of cash that employees have access to as a deterrent to robberies that can be associated with assaults on workers (Fig. 24-4). Worker training, which is essential to the implementation of safe work practices and procedures, is also considered by many safety and health professionals to be an administrative control. The use of training as an injury prevention strategy is discussed in further detail in the section on Training, later.

Personal Protective Equipment

The use of PPE is common in many work environments, and in many situations, essential for worker protection. However, PPE is usually viewed as the last tier of the protection hierarchy. If hazardous exposures cannot be eliminated or controlled through equipment design or the application of engineering or administrative controls, then PPE provides another opportunity for worker protection. Examples of PPE designed for reducing worker injuries include protective hard hats, eye wear and face shields, steel-toed safety shoes, fall restraint devices, and personal flotation devices. When worn properly and consistently, these devices can prevent or at least reduce the severity of traumatic injury. Fall restraint devices (e.g., lanyards and body harnesses) do not prevent a worker from falling, but protect workers from a more serious injury or fatality from a fall event when working at elevations, such as on a roof (Fig. 24-5).

In most work environments, a combination of engineering controls, administrative controls, and PPE is required to have a complete and effective injury prevention program. The following examples illustrate how the combined application of controls can be used to achieve an enhanced level of worker protection.

Tractors equipped with a rollover protective structure (ROPS) significantly reduce the risk that the operator will be injured in a rollover event (Fig. 24-6). However, additional protection can be achieved if a seat belt is worn to keep the operator within the protective envelope of the ROPS. A similar example is the increased protection afforded by the use of seat belts, mandated in company safety policies and programs, in motor vehicles that are also equipped with air bags.

FIG. 24-5. Ironworker using a full-body harness and lanyard attached to a rope grab. This worker has the flexibility to move up the structure while maintaining fall protection. (Photograph courtesy of the Construction Safety Council.)

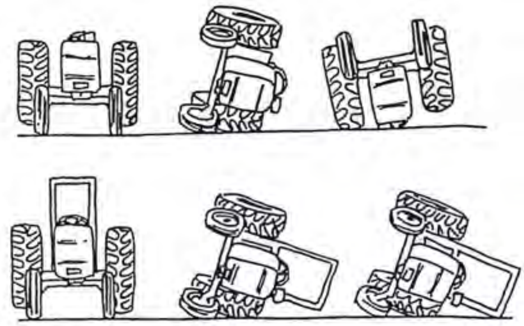

FIG. 24-6. Tractor with a two-post protective rollover protective structure (ROPS) frame installed. ROPS are designed to reduce the risk of injury or death by preventing the tractor from rolling onto and crushing the operator. A properly fastened seat belt greatly improves the chances that the operator will stay within the protective envelope provided by the ROPS (i.e., the seat). (From National Institute for Occupational Safety and Health. Safe grain and silage handling. DHHS (NIOSH) publication no. 95-109. Cincinnati, OH: National Institute for Occupational Safety and Health, 1995.)

Training

Training refers to methods to assist workers in acquiring knowledge (safety information), changing attitudes (perceptions and beliefs regarding safety), or practicing safe work behaviors (organizational, management, or worker performance). Despite a paucity of data on the direct relationship between training and injury, there is evidence showing a positive impact of training on establishing safe working conditions (15). Research indicates that training is one of the key factors accounting for differences between companies with low and high injury rates, and in developing and implementing effective hazard control measures (15,16). Training increases hazard awareness, knowledge and adoption of safe work practices, and other workplace safety improvements.

Characteristics of effective training programs include assessing training needs specific to the work task; developing the training program to address these needs specifically; setting clear training goals; and evaluating the posttraining knowledge and skills and providing feedback of these results to the workers (16). There are also indications that training is more effective when coupled with organizational support and management commitment to safety, and when it emphasizes early indoctrination and follow-up instruction and reinforcement (15,16).

Unique characteristics of the specific workforce must be considered when developing or implementing safety training programs. Language, literacy, cognition, and cultural issues may diminish the effectiveness of training when programs are not tailored to account for unique or diverse characteristics of the workforce. Workplace safety training appears to be most effective when it includes active learning experiences stressing job site applications, and when it is placed in the context of a broader, workplace-based prevention approach (15).

Standards

There are many standards aimed at protecting workers from traumatic injury. These standards cover a multitude of hazards and address the work environment, work practices, equipment, PPE, and worker training. There are primarily two types of worker protection standards: mandatory standards, such as those promulgated by a regulatory agency such as the Occupational Safety and Health Administration (OSHA); and voluntary standards, such as those developed through independent organizations like the American National Standards Institute through a consensus process involving various stakeholders in an industry, such as representatives from labor, management, and government. There are also numerous specifications, codes, and guidelines for machinery, equipment, tools, and other materials that can assist engineers and designers in developing safer products and systems, many of which have application in the occupational setting. Examples include the National Electric Code, published by the National Fire Protection Association, and numerous consensus standards from the American Society of Mechanical Engineers and the American Society for Testing and Materials.

The OSHA standards are the primary federal regulations governing workplace safety and health for all industries except mining. The OSHA standards are codified under Title 29 (U.S. Department of Labor). Title 29 CFR (Code of Federal Regulations), Part 1910 *Occupational Safety and Health Standards*, covers General Industry, Maritime and Agriculture, whereas 29 CFR 1926 includes *Safety and Health Regulations for Construction*. Title 29 also provides standards under Chapter V, Wage and Hour Division, that address child labor issues. Safety and health standards for the mining industry are promulgated by the Mine Safety and Health Administration under Title 30 CFR 1 to 199, Chapter I. (See Chapter 10.)

Injury Control: Roles and Responsibilities

Occupational injury prevention is not the sole responsibility of a single person or group. Employers, workers, regulators, and policy makers each share in the responsibility for prevention. A multidisciplinary approach involving interaction among diverse groups in an organization and active participation by both management and workers are crucial to an effective safety program.

Employers are responsible for establishing written safety policy, developing a comprehensive safety program, and effectively implementing that program at the worksite. A competent person or committee should be designated with responsibility for company safety policy. This person or committee should have knowledge of safety policy, standards, regulations, and hazard abatement, and should actively participate with management and employees in overseeing the safety program.

An effective safety program strives to identify hazards through job safety analysis or other methods of systems safety analysis, and eliminates or controls identified hazards through the various approaches previously discussed. Workers, managers, and safety specialists should work together to analyze the job and potential hazards, and to recommend changes or controls to abate them before an injury event occurs. In industries or jobs where the worksite is not constant, site hazard assessments should be performed before beginning work in any new environment. Occupations such as farming, logging, construction, and mining are characterized by frequently changing worksites, and require a site hazard assessment before commencing work in any new or changed environment. This is particularly important in construction, where worksites change not only from job to job, but from day to day, even hour to hour, with constant potential for new hazards.

Employers are also responsible for ensuring proper maintenance of vehicles, equipment, and machinery, and their safety features, such as machine guarding, interlocks, and barriers. Where job hazards cannot be eliminated or controlled, employers are responsible for providing appropriate PPE, such as fall restraint systems, respirators, hearing protection, hard hats, or eye protection.

Employers must also ensure that workers receive appropriate training in minimizing their risk, including safety policy and practice, hazard recognition and control technologies, and the appropriate use of PPE. Enforcement of safety policy is also a critical employer responsibility. Management's demonstrated commitment to safety has been recognized as a major factor in successful workplace safety experience (17,18). Employers who demonstrate concern and support for safety activities have top managers personally involved in safety activities, and routinely involve workers in safety matters and decision making. These employers are more likely than others to have successful safety programs. As part of a comprehensive safety program, employers should require systematic reporting or surveillance of occupational injuries, and assessment of these data for use in corrective action to prevent similar occurrences.

Workers also play a vital role in workplace safety. Workers share in the responsibility for complying with safe work practices and policies, maintaining a safe workstation, and using appropriate PPE as required by their employers. Workers should also participate in company-sponsored safety training and reporting unsafe conditions for corrective action. Participation of workers in the workplace safety program is essential; as the experts in their jobs, workers should be involved in safety analysis and development of safe solutions. Worker input into recommended design or modification of safety controls, processes, or technology, and into the development of safe work practices, increases the acceptance of positive changes and, thus, the success of the safety program.

An effective workplace safety program that minimizes injuries results from a multidisciplinary effort that actively involves every level of the workforce, from the employer and upper-level managers to employee representatives and hourly workers. Each must assume some responsibility for safety and must work together interactively to achieve the common goal of preventing injuries.

Occupational injuries continue to exert too large a toll on the workforce. Reductions in fatal and nonfatal injuries from earlier periods demonstrate that progress can be made (1,2,4,9,19). However, progress requires concerted and consistent efforts from multiple parties using multiple strategies. In addition to the primary stakeholders in the workplace, additional groups can help reduce occupational injuries. These groups include manufacturers and distributors of industrial equipment and tools who design and promote safety features of equipment, insurers who provide monetary incentives for good safety records, and health care providers who give their patients information on preventing workplace injuries.

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