Chapter 1

A Public Health Approach to Preventing Occupational Diseases and Injuries

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Each year in the United States, 5000 to 6000 workers die from acute traumatic occupational injuries. The same industries report the highest rates of fatal injury every year—underground mining, construction, agriculture-forestry-fishing, and transportation. The construction, manufacturing, and agriculture sectors report the highest rates of nonfatal injury. Consistently, the most common causes of occupational injuries are motor vehicle crashes (on and off the road), violent acts and homicide, and falls from heights. Strains and sprains are the most common types of reported injuries, with back injuries accounting for the most lost time. There is, in short, sufficient knowledge to anticipate the potential for and types of many fatal and nonfatal occupational injuries in order to direct preventive efforts.

Similarly, the causes of, and methods to prevent, many occupational diseases are well known. The causes of some diseases, such as lead poisoning and silicosis, have been known since antiquity; successful prevention and control methods have been available for many decades. Dermatitis, musculoskeletal injuries, and noise-induced hearing loss continue to occur, despite many advances in our understanding of their causes and how to prevent them. With the development of more sophisticated means to measure exposures, identify subclinical effects, and process large amounts of information, more occupational causes of disease are being identified, including the occupation-attributable fraction of such common ailments as cancer, cardiovascular disease, and stress-related conditions.

Work can be hazardous. More importantly, most hazards can be anticipated. Knowledge about hazards and the methods to control them exist in many places: the scientific literature, regulatory agencies, workers' compensation organizations, the collective experience of workers and their employers, insurance companies, industry and trade organizations, labor unions, health and safety professionals, and elsewhere. At times, this knowledge is acquired and applied only after injuries, illnesses, or even catastrophes have occurred.

The following represents a systematic public health approach to preventing occupational diseases and injuries. (See Figure 1 on page 8.)

Anticipation

Anticipation is the cornerstone of the public health approach to controlling occupational disease and injury. It is a concept that merges two important elements: prediction and action. According to the *New Oxford American Dictionary* (2001), to anticipate is "...to expect or predict;...to take action in order to be prepared." In occupational health, anticipation involves an active expectation that hazards will occur, and an obligation to take action to eliminate or control them before harm occurs. Thus, occupational health and safety professionals have critical tasks to perform. They must (1) acquire the knowledge necessary to prevent disease and injury, (2) use it to anticipate problems, and (3) intervene to prevent their occurrence and reoccurrence. Occupational disease and injury are not an inevitable part of work.

Anticipation can take many forms. These include factoring worker health and safety into the design of work, workplaces, and work processes and practices and into the selection of safest/least hazardous materials and methods. Training and educating workers, managers, and health and safety employees about aspects of workplace technologies are also key. Preplacement and return-to-work medical examinations can play a role in anticipation and prevention. When coupled with the necessary and specific information about the workplace and demands of a job, an understanding of a worker's abilities and limitations can help predict and prevent future problems. Other aspects of anticipation include promoting good labor-management relations, forming active worksite health and safety committees, and eliminating payment and incentive mechanisms that encourage supervisors and workers to cut corners. Worksite-specific policies as well as overarching public policies and regulations can stimulate and support these efforts.

When employers and other decision-makers create or modify workplaces, they routinely anticipate and consider many factors, such as the price and accessibility of materials, the availability and training of the workforce, the most appropriate and efficient work methods and technologies, proximity to markets, and transportation. Health and safety hazards must find their place among these factors. Decision-makers should incorporate hazard control into their planning and decision–making processes. Then, steps to protect worker health and safety can be taken early in the design phase, before commitments are made that will be difficult and expensive to change—literally before they are cast in concrete.

Hazards Inventory

A comprehensive hazards inventory can be a useful tool in the anticipation and recognition of risk. Hazards can be inventoried by their form and route of exposure (Table 1) and can be evaluated with estimates or measurements of exposure combined with an assessment of potential harmful effects. This haz-

Table 1. Hazards Inventory

I. Physical Hazards
- A. Noise and vibration
- B. Extremes of heat and cold
- C. Radiation
- D. Barometric pressure
- E. Other

II. Ergonomic
- A. Repetitive motion
- B. Excessive force
- C. Awkward posture
- D. Other and aggravating conditions

III. Chemical Hazards
- A. Inhalation
  - 1. Particulate matter
  - 2. Gases and vapors
- B. Skin Absorption
- C. Ingestion
- D. Other routes

IV. Biological Hazards
- A. Infectious microorganisms
- B. Chemical hazards of biological origin
- C. Animals and plants

V. Psychosocial Hazards
- A. Work load; speed and hours of work
- B. Control over work
- C. Social isolation
- D. Work organization
- E. Abusive social environment

ards inventory involves a systematic enumeration of physical, ergonomic, chemical, biological, and psychosocial hazards present in the workplace; the routes of exposures; and an estimation of the frequency and intensity of potential exposure.

Physical hazards are different forms of energy. These include noise, vibration, ionizing and non-ionizing radiation, extremes of temperature and of barometric pressure, and rapid change in barometric pressure. In general, risk of injury increases with the energy level. Specific hazards are described in more detail in Part II (see, for example, Hearing Loss, Noise-Induced; Radiation, Ionizing and Nonionizing; Hyperbaric Injury; Injuries, Fatal and Nonfatal; and Heat Stress). Circumstances that can result in acute traumatic injury, such as working at heights or on busy highways, are also physical hazards.

Ergonomic hazards are physical motions or positions that may cause acute or chronic injury. These include repetitive or awkward motion, excessive force, flexion or extension, or awkward or static posture. Effects of these hazards are aggravated by stress, temperature extremes, work organization, and other environmental factors. (See, for example, Part II chapters on Upper–Extremity Musculoskeletal Disorders; Carpal Tunnel Syndrome; Tendonitis and Tenosynovitis; Peripheral Nerve Entrapment; and Low Back Pain Syndrome; and the Part III chapter on Work Organization.)

Chemical hazards are classified as solids, liquids, or gases that most commonly enter the body by inhalation, ingestion, or absorption through the skin. Harmful effects depend on the nature of substances, the magnitude of exposure and dose, and the duration of exposure. Inhalation is the most common route of entry for chemical hazards, although chemicals may be ingested if they contaminate food, drink, or smoking materials or are coughed up and swallowed. Evaluating the potential health effects of airborne particles (dusts, mists, and fumes) requires knowledge of their identity and concentration, as well as information about their size (diameter). Particle diameter determines the site of their deposition in the lung which, in turn, determines the site of injury and whether the particle is absorbed systemically (see Box). Some explosive and flammable gases and vapors, organic particles, such as coal, grain, and sugar, and some metal aerosols, such as magnesium and aluminum, may also create risk of fire or explosion.

Biological hazards include infectious microorganisms, plant or animal toxins, and animals. Microorganisms may (a) cause frank disease, such as viral hepatitis or Lyme disease; (b) cause allergic reactions, such as those associated with molds; (c) deplete oxygen; or (d) produce toxic gases. Plants may produce toxins. Animals may attack and transmit infections to zookeepers, veterinarians, postal delivery workers, and other workers. These hazards are described in Part II chapters on such topics as Human Immunodeficiency Virus (HIV) Infection; Tuberculosis; Hepatitis, Viral; and Zoonoses.

Psychosocial hazards result from a complex interplay of job demands, skills, decision-making latitude, personal control of work, work organization, and social interactions. (See Part II chapters on Stress, Collective Stress Disorder, Depression, Post-Traumatic Stress Disorder, Homicide and Assault, and Suicide, and the Part III chapter on Work Organization.)

Recognition

Hazard inventories coupled with knowledge and experience related to the workplace, work processes, and workforce are valuable tools for anticipating

Box

Aerosols

- Particles less than 5–10 µm in diameter are called respirable. They are likely deposited in the alveoli and terminal brochcioles where gas exchange occurs.
- The relative solubility of aerosols, gases, and vapors also affects the site of deposition and injury or absorption, with the more highly water soluble likely to be absorbed in the upper airways.
- Respirable particles are more likely to be retained and absorbed than large particles and thus cause lung injury or systemic disease.
- Repetitive deposition of aerosols in the airways may result in chronic airway irritation.
- Extremely small particles may behave differently and may be absorbed and distributed systemically.

health and safety risks and implementing prevention strategies. However, ongoing monitoring of hazards and of the health of workers is needed to identify and respond to changing or unanticipated risks to health and safety in both stable and unstable work environments. Surveillance, or tracking, of workplace hazards and worker health can help in the recognition of risk and adverse effects.

Surveillance

Surveillance, as defined in the *Dictionary of Epidemiology*, is "the ongoing scrutiny [of the occurrence of disease and injury], generally using methods distinguished by their practicality, uniformity, and frequently their rapidity, rather than by complete accuracy. Its main purpose is to detect changes in trends or distributions in order to initiate investigative or control measures." Surveillance is a fundamental part of public health practice. A surveillance system for occupational disease and injury control should (a) acquire information about hazardous exposures and diseases and injuries (outcomes), (b) analyze this information, and (c) disseminate and interpret it to those who need it. Mere information-gathering is not sufficient; the point of surveillance is to prevent disease and injury, not only to document its occurrence. Thus, a surveillance system must be linked with the capability to investigate further and to intervene to prevent disease or injury.

Surveillance strategies differ for acute and chronic health outcomes. For acute conditions, in which the time between exposure and outcome is short and/or the relationship of outcome to work is apparent, exposures and conditions that have caused disease or injury are more easily identified and controlled. Specific causes are more difficult to identify for chronic conditions, which are often multifactorial in nature but may result from long-term and/or low-level exposure or appear after many years (latency). The exposures that caused the disease may have changed or disappeared by the time the disease becomes clinically apparent. Even if the exposures that caused the disease remain in the workplace, the disease may not occur until late—well after the worker leaves the workplace for another job or to retire. Moreover, for irreversible conditions, control of hazards is effective at preventing disease or injury only prospectively and cannot correct harm that has already occurred. Therefore, surveillance for some chronic or long-latency health effects should persist even after hazards are controlled.

Identification of hazards that cause chronic effects often requires more knowledge than is available from a single workplace or population of workers. Information gleaned from the literature or from professional sources knowledgeable of problems in other settings may establish the need for controls. It is not prudent to wait for the development of chronic disease in any single workplace before reducing exposure that has caused problems elsewhere.

For both acute and chronic conditions, surveillance of exposures and of outcomes can be practiced both inside and outside specific workplaces. At the level of individual workplaces, surveillance involves systematic workplace inspections, measurement and evaluation of exposure, examination of workers, recordkeeping, and reporting of health effects and exposures. Surveillance at the workplace is thus an essential ingredient for managing a disease and injury prevention program. When practiced in settings apart from individual workplaces—for example, at local, state, or national agencies, hospitals, or disease or injury registries—surveillance can involve acquiring and analyzing data from a wide variety of sources, including employer reports, workers' compensation claims, hospital records, police reports, disease registries, and poison control centers. Regardless of the source of surveillance data, however, most information arises from workplaces, and intervention must eventually focus on workers, employers, and workplaces.

Hazard Surveillance

Workplace inspections should occur regularly to identify new problems and ensure that existing controls and prevention strategies are adequate and maintained. They also should be conducted (a) immediately after injuries, accidents, or near-misses occur to identify manifest and root causes; and (b) when someone on the job suspects a problem and requests an inspection. Inspections may be required by statute or regulation, by some insurance carriers, or by a labor-management contract.

Inspections can be conducted by health and safety committees, workers at the job site, health and safety professionals, engineers, or inspectors from outside the workplace, such as those from regulatory agencies, insurance carriers, parent corporate offices, or labor unions. Workers have regular and sustained experience with the workplace and are essential witnesses to circumstances surrounding specific incidents. Both employers and employees should be represented to ensure a balanced and full assessment of the hazards. Safety engineers bring needed expertise and experience to any inspection. Inspections by people not in daily contact with a job, such as government inspectors, insurance agents, or experts from parent corporations or unions, bring fresh perspectives and knowledge of pertinent regulations and guidelines. They may also bring needed incentives in the form of citations, changes in insurance rates, and other penalties or rewards.

Regardless of the reason prompting them, inspections are an important source of data for use in later analysis. Therefore, information should be documented in a consistent form. Periodic inspections not related to particular incidents should be systematic and custom-made for each workplace or industry. Checklists and a plan to visit every job site are useful. A walk-through survey should follow the flow of work from start to finish, accounting for uses, storage, waste, byproducts, disposal of all materials, and maintenance operations. Results should be documented and discussed by a work-site committee. Records of prior inspections, committee meetings and actions, and injuries should be available to monitor performance. The frequency of inspections depends on the degree of hazard. In the high-hazard underground coal mining industry, for example, certain inspections are required by statute prior to each work shift.

Employers are legally required to record work-related injuries that result in medical treatment, time away from work, and restricted activity. These records may be obtained by the Occupational Safety and Health Administration (OSHA) or by workers and their representatives. At a specific workplace, these records are useful surveillance tools. Although intended to cover both diseases and injuries, these records are inherently more likely to reflect acute conditions, such as traumatic injuries, and certain acute diseases, such as contact dermatitis and acute poisoning, than chronic conditions. Under the Mine Safety and Health Administration (MSHA), records of injuries and accidents are required to be reported (not merely recorded) and are available from MSHA.

Monitoring and measuring some occupational hazards are required by law. Employers under OSHA jurisdiction are required to maintain exposure records and make them available to OSHA or to workers or their representatives. When analyzed collectively, surveillance data can be used to identify potential hazards and, in some instances, to estimate exposure for individuals or populations over the period the regulations have been in effect. Exposure monitoring data for the mining industry are available from MSHA.

Medical (Health) Surveillance (Biological Monitoring of Effects)

The purpose of medical surveillance is to promote prevention by identifying the distribution and trends in the occurrence of disease and injury in populations. Outcome measures may range from individual signs and symptoms to well-defined diseases. Most often, medical surveillance results in secondary rather than primary prevention, because it can only identify individuals already affected by occupational exposures. When combined with hazard surveillance, however, analysis of medical surveillance data can complement primary prevention efforts by also identifying hazards. Surveillance is distinguished from screening (described below) by its concern with a target population; screening is primarily concerned with individuals.

Medical surveillance may be conducted at specific workplaces or in community settings. Employer medical departments usually have easy access to workers and to workplaces and thus are well situated to detect acute conditions, monitor active workers' health regularly, link medical with exposure data, and implement programs for the early detection and prevention of occupational conditions. Conditions caused by multiple exposures at different workplaces and chronic conditions that may not appear until after retirement are harder to detect by workplace-based surveillance programs. Moreover, workplace-based medical departments serve only a small minority of the working population—usually those situated in large or exceptionally high-risk workplaces.

Surveillance efforts that are based on data from the community, clinical settings, and registries complement workplace surveillance programs. Such efforts may be designed and implemented by government agencies, hospitals, or clinics, or they may be based on networks of health care providers. For example, the Sentinel Event Notification System for Occupational Risk (SENSOR) program developed by the National Institute for Occupational Safety and Health (NIOSH) and implemented by some states is a small-scale model of disease surveillance for selected disease outcomes with well-defined clinical features. The states may use several data sources, including case reports from a select group of health care providers, hospital discharge data, and workers' compensation data. A state agency collects and analyzes the information and reports and follows up to help activate preventive measures.

Medical surveillance may be active, in which populations of workers are selected, recruited, and examined, or it may be passive, relying on existing data collected at medical facilities for other reasons. Passive surveillance usually detects only symptomatic disease and cannot be relied on to uncover conditions earlier in their natural history. It also requires that health professionals be able to recognize the effects of occupational exposures in individuals in clinical settings. Because many occupational and nonoccupational diseases resemble each other and because occupational diseases are only suspected when an exposure history is obtained, passive surveillance cannot be relied on to detect many work-related diseases without a complementary effort to assess occupational exposures.

Active surveillance for work-related conditions requires assessment of exposure prior to conducting surveillance in order to define and select the appropriate population. Workers selected for active surveillance are usually at high risk for disease or injury. Selection criteria include assessment of current or past exposure based on measurements (if possible), employment history, or similar parameters. Because health effects depend on the identity of hazards, exposure assessment is also required prior to selecting medical testing procedures. For example, workers exposed to lead should receive regular laboratory tests for blood lead levels; workers exposed to silica, chest x-rays; and workers exposed to noise, audiometric examinations.

The occupational contribution to illness often cannot be recognized when individuals are considered in isolation from similarly exposed workers. Thus, results of surveillance should be analyzed in populations classified by exposure. Basic epidemiological methods are used to analyze such data, so that when aggregate findings are linked with assessment of occupational exposure, the results can be used to identify, evaluate, and control hazards.

Medical Screening

The purpose of medical screening is the early detection of disease or conditions for which treatment can successfully affect morbidity or mortality. Screening is a form of secondary prevention. Medical screening programs at work can provide the data for ongoing population health surveillance efforts. Screening usually consists of performing physical examinations and specific tests for the purpose of detecting disease at an early treatable or remediable stage. Ideally, screening should be designed and administered within an overall program that identifies people at risk, educates and informs them about the screening program, implements the screening program, and appropriately follows up with diagnostic tests on those who screen positive and with treatment for those who have disease.

Various types of screening tests are relevant to occupational health, ranging from pulmonary function tests that help detect respiratory impairment associated with work-related lung disease to tests and procedures for the early detection of various types of cancer. Important considerations in a screening program include the sensitivity of a test (the degree to which it correctly identifies those with the disease or condition), the specificity of a test (the degree to which it correctly identifies those without the disease or condition), and predictive value positive (the likelihood that a person who screens positive for a disease or condition actually has that disease or condition). There is often a trade-off between sensitivity and specificity in choosing among various screening tests and in determining a cut-off for abnormality in a given screening test; that is, a highly sensitive screening test is likely to be less specific, and a highly specific screening test is likely to be less sensitive. While screening is considered secondary prevention, it can indirectly identify hazardous workplace situations and lead to effective primary prevention.

Biological Monitoring of Exposure

Biological monitoring is a form of surveillance to estimate exposure based on biological assays of material, such as urine, blood, and exhaled air, collected from workers. Data from such examinations may be an important complement to industrial hygiene and can provide data for formal epidemiologic investigations. However, biological monitoring should never be a substitute for effective environmental monitoring of toxic exposures, and, since the difference between a biomarker of exposure and a sign of injury may not be clear, the potential ethical implications of biomonitoring should always be considered.

Sentinel Health Events

Intervention is an essential part of surveillance. If surveillance reveals the presence of a Sentinel Health Event/Occupational (SHE/O), identifies sick or injured people, or identifies people with preclinical signs or symptoms or other effects, multiple interventions should be considered: (a) referral of affected individuals to appropriate diagnostic and treatment services, (b) investigation of the workplace for identification of possible additional cases and causes, (c) implementation of measures to control the causative or excessive exposure, (d) provision of information about state workers' compensation programs and benefits, and (e) reporting of findings to the affected group of individuals and to the relevant authorities. Conditions that are considered to be SHE/Os are indicated as such at the start of some chapters in Part II.

Evaluation

Systematic analysis will help determine if intervention to control hazards is needed and will help inform the intervention effort. As illustrated in Figure 1 (see page 8), control is required (a) when there is excessive exposure, (b) when epidemiological or toxicological analysis demonstrates a positive relationship between exposure and health outcome, or (c) when occupational diseases are manifest. Several disciplines and tools can be critical aids in analyzing and evaluating data and other information obtained through surveillance and screening efforts. Below, we describe selected issues in epidemiological and toxicological investigations and in exposure measurement.

Epidemiology

Epidemiology is the study of the occurrence, distribution, and determinants of disease and injury in populations. It is an observational rather than an experimental science. Events and associations are explored in the actual contexts in which they occur rather than in experimental settings. The value of epidemiology comes at the expense of not being able to control variables directly and with the constraint of having to conduct studies on available populations.

Epidemiological investigations of occupational disease and injury are used for decision-making in much the same way as they are in other aspects of public health practice. The purposes of occupational epidemiology are to (a) identify and assess causes of disease and injury and, thereby, (b) identify opportunities for prevention, (c) evaluate or determine exposure limits, and (d) evaluate control measures.

The principal tasks of epidemiologists are formulating hypotheses to investigate, developing suitable study designs, selecting study and comparison groups (with respect to size and composition), determining and analyzing outcome data in relation to various factors, addressing potential sources of bias and confounding, and drawing conclusions from studies. The aim is to increase the probability that observations of associations (or the lack of associations) between exposures and health effects are valid. This is done by controlling, to the extent feasible, selection, observation, and random bias, and by analyzing data for confounding.

Solving problems of bias and chance does not, by itself, directly address the question of whether an outcome is, in fact, caused by a particular exposure or condition. In evaluating the relevant medical and scientific literature to determine whether exposure to a specific chemical or other factor likely caused a disease or medical condition, one should consider (a) the soundness and relevance of each individual study (methodology, results, and conclusions); and (b) the overall body of applicable scientific information. To help determine causality, guidelines or principles have been developed, including:

(a) Temporality: The disease or injury occurred after the exposure.
(b) Strength of Association: The magnitude of risk, such as the relative risk, associated with the purported cause is large.
(c) Consistency: There is general consistency of the results among relevant studies.
(d) Biologic Gradient: There is a positive dose–response or exposure–response relationship.
(e) Plausibility: Given current scientific information, the association is biologically plausible.

(f) Coherence: A cause–and–effect interpretation for an association does not conflict with what is known of the natural history and biology of the disease.

Only the first of these is essential in establishing a cause–and–effect relationship.

A conclusion that a demonstrated association reflects a cause-and-effect relationship is usually based on some, but not all of these factors, and a sound integrative assessment of the strengths and weaknesses of the available data. Conversely, the adage "Absence of proof is not proof of absence" is critically important in determining whether to continue to attend to suspected hazards when available epidemiologic studies do not support a causal association or appear "negative." These issues are not unique to occupational health studies; they are frequently encountered throughout public health and are discussed extensively in public health and epidemiology textbooks.

An important factor in occupational epidemiology involves the select nature of working populations. Participation in the labor force is restricted for some people who are disabled and/or chronically ill or injured; other people are selected out when they become ill or injured. In the United States, access to health care is often determined by work status, and people with better health care access may have better health. These selection processes result in the "healthy worker effect," in which workers as a group are somewhat healthier than those not working. Since adverse health effects can appear after departure from the workforce or may cause early departure from hazardous jobs, it is often necessary to select comparison populations, also composed of workers, and to find former or absent workers and determine their health status.

Working populations that are studied are also select groups. Because of practical limits on the availability of sufficiently large populations, the workers and the occupational hazards that epidemiologists study are often in larger workplaces or companies that have low turnover and are accessible. Epidemiologists are less likely to investigate workplaces that are small and widely dispersed, where labor turnover is high, or where there are significant obstacles to their accessibility. Such workplaces present significant logistical problems. Part-time, undocumented, and self-employed workers are unlikely to be studied.

Toxicology and Biochemistry

Toxicology and biochemistry are also useful disciplines for evaluating hazards. The toxic effects of many exposures are known primarily by their effects on animals or through biochemical investigations using bacteria or other cells. Information from such investigations can help evaluate biological plausibility and disease mechanisms. Dose–response relationships can also be evaluated. Risk to humans can be estimated by considering differences in physiology and by comparing the biochemical or toxicological potency of some substances with that of other substances whose effects on humans are better understood.

The clear advantage of toxicological and biochemical investigations are that they are experimental. Dose (as distinguished from exposure) and bias can be controlled, and outcome can be assessed to a degree unmatched in epidemiological investigations. The disadvantages are that investigators must extrapolate from one species to another and often from high to low dose, or they must make inferences from a biochemical reaction in cells to effects in whole organisms. In making extrapolations, investigators must compare humans with other animals concerning disease mechanisms and routes of exposure (such as whether the substance was inhaled, ingested, or injected). To aid in assessing risk, NIOSH and regulatory agencies such as the Environmental Protection Agency (EPA) and OSHA have developed methods of extrapolation.

Exposure Assessment

Exposure Measurement: Exposure measurement provides a more precise assessment of the hazard. Measurement of exposure is appropriate when hazards are suspected or reasonably predictable based on a hazards inventory combined with an assessment of work practices. Measuring exposure is done to (a) identify hazards in order to implement controls, (b) evaluate controls, (c) determine compliance with standards, and (d) assess exposure for epidemiologic research.

The basic parameters for measuring exposure to chemical and physical hazards are

- the concentration or intensity of exposure (measured volumetrically [ppm] or gravimetrically [mg/m^3], or by energy units [such as dBA and mSv]);
- the duration, frequency, and latency of exposure; and
- the determinants of exposure.

The determinants of exposure are those variables inherent in any occupational setting that affect exposure and are roughly classified as the conditions of use and the labor process. These concepts are applicable to jobs in either goods-producing or service sectors. The conditions of use include the level of production, the nature and form of raw materials, products and byproducts, maintenance processes, and use of industrial hygiene controls. The potential for accidental exposures from spills or breakdowns can be estimated with the assistance of people on the job: workers, supervisors, maintenance personnel, and others.

The labor process includes what workers do that affects exposure. This can include, for example, where and how they sit or stand, when and how they do certain parts of their jobs, whether they use personal protective equipment, the circumstances under which they might take a break, and so on. Some experienced workers may know certain "skills of the trade" that enable them to reduce exposure and these may be passed on to less experienced workers.

Measurement methods depend on the particular hazards and circumstances under which exposure occurs. Airborne hazards are typically measured by analyzing a sample of air at a particular point in time (a "grab sample") or averaged over an appropriate time period (a time-weighted average, or TWA), such as a work shift. Most exposure limits are linked to 8-hour work shifts. Work shifts, however, are becoming increasingly varied in length requiring more interpretation of exposure measurements. Standard methods in the United States have been developed by NIOSH in its *Manual of Analytical Methods* (available at the NIOSH website).

Some novel exposure measuring methods have been developed for measuring exposure associated with tasks (rather than work shifts) and for identifying controls. Task-based exposure assessment must be designed for the duration of each task. This type of exposure measurement can then link exposure and the need for controls to specific tasks. Real–time monitoring—linking a real–time instrument with a video camera and recording a task while simultaneously measuring exposure—is a useful tool for identifying specific sources of exposure and thus for developing controls.

Exposure varies. The major sources of variation are associated with the source itself as the determinants of exposure change. Sampling and analytical error, inherent in any measurement, is typically a smaller source of variation. Any sampling strategy should be able to account for variability by an appropriate selection of the type, number, and timing of samples and a written report should identify the sources and include measurements of variability.

Standards and Exposure Limits: Measurements are often evaluated by comparison with exposure limits and standards. Some standards are legal requirements; others are not. Legal standards are set by federal, state, or local governmental regulatory agencies. Setting standards is governed by the nearly identical language of the OSHAct and the MSHAct. (See next chapter on Occupational Health and Safety Law.) If exposure exceeds a legal standard, the employer is obligated to reduce it. If exposure exceeds a standard that is not a legal requirement, a public health need may dictate reducing exposure, but legal resources for compelling reduction may be lacking. The principal federal regulatory agencies involved in setting workplace health and safety standards are OSHA and MSHA, both in the Department of Labor. Both agencies set legally enforceable exposure limits for toxic substances or other hazards called permissible exposure limits (PELs). These are limits based on a

TWA exposure; they also set some short-term exposure limits (STELs or ceilings), and, for some hazards, conditions that might result in skin absorption. PELs exist for about 600 chemical substances commonly found at workplaces.

Exposure limits proposed by the American Conference of Governmental Industrial Hygienists (ACGIH) (threshold limit values, or TLVs, and biological exposure indices, or BEIs) and by NIOSH (recommended exposure limits, or RELs) do not have the force of law. Although most are identical with PELs, there are many differences. For example, only the ACGIH has proposed BEIs, some TLVs cover topics not covered by OSHA or MSHA (such as heat stress and ultraviolet radiation), and many TLVs and RELs for airborne hazards are more stringent than PELs. RELs are not required to meet the "feasibility" test of PELs.

There are limits in the scope, completeness, and enforcement of workplace health and safety standards. Inevitably, therefore, health effects associated with work can occur with little or no evidence of exceeding an exposure limit. In these situations, it may be necessary to investigate the work environment in detail to identify the potential causes of workers' ill health. Federal, state, or local public health agencies may conduct small- or large-scale epidemiological investigations; both the OSHAct and the Mine Act provide for health hazard evaluations (HHEs), which generally are more focused investigations of health problems in a specific workplace. These investigations are conducted by NIOSH and can be requested by employers or by workers or their representatives. The names of requestors may be kept confidential. To request an HHE, contact NIOSH.

Control Banding: Measuring exposure can be expensive and time-consuming and, in some cases, it may be unnecessary, impractical, or impossible, especially for small enterprises and companies in developing countries. A recently developed approach to assessing chemical exposures to guide decisions about control is called control banding. This method is relatively simple and intuitively appealing. It:

- organizes chemicals into exposure classes based on their hazard classification according to international criteria,
- determines the amount of each chemical in use,
- assesses its volatility/dustiness, and
- considers the number of workers potentially exposed.

This information is then used to apply conventional industrial hygiene control methods (see discussion of exposure control, below) or to seek specialist advice.

The control banding concept has been used in specific circumstances by a variety of organizations. The Health and Safety Executive (HSE) of the United Kingdom and the International Labor Organization (ILO) have developed tools that assist safety officials and employers in applying control banding techniques in the workplace (see http://www.coshh-essentials.org.uk and http://www.ilo.org/public/english/protection/safework/ctrl_banding/index.htm).

Such an assessment provides useful and sometimes sufficient information for making rational decisions about the need for intervention or the adequacy of existing controls. It may also assist in making decisions about the need for more formal and rigorous evaluations, including exposure measurements.

Clinical Assessment

Clinical evaluation of an individual worker or group of workers enables physicians and other health care providers to determine the nature of worker illnesses and injuries and their degree of work-relatedness. Information for the assessments is collected through medical and occupational histories, physical examinations, and/or various laboratory, imaging, and other clinical tests. Information obtained clinically needs to be reviewed in the context of, and integrated with, information obtained on exposures and working conditions, along with relevant medical and scientific literature regarding possible causal associations between workplace exposures and adverse health effects. Clinical assessment can also identify problems early, thus helping to assess future health risks that a worker may be facing and ideally stimulating the implementation of preventive measures to reduce these risks.

Risk Assessment

Risk assessment is a process that we use intuitively on a regular basis. We use it when we suspect or identify a problem. Generally, we try to characterize the problem, assess its magnitude, estimate the likelihood of harm, communicate our thinking to others if needed, and use all this to determine a course of action. Individuals use this basic process in many arenas—from making decisions about health and lifestyle issues to deciding how to handle finances. Health care professionals assess the risks and benefits when providing medical care to patients. Employers, workers, and occupational health professionals do this in the context of assessing and controlling workplace health and safety hazards.

In the context of public policy, risk assessment is a more formalized and rigorous process. Regulatory agencies increasingly conduct risk assessments in the course of making regulatory or policy decisions about occupational and environmental exposures. Often, the final product of a formal risk assessment is a statement such as, "The lifetime risk of this illness increases by 10^{-5} (one per 100,000 population) with each increase of each 1 mg-year/m^3 of exposure."

The appeal of risk assessment is the creation of a common metric—the probability of illness or injury—that can be used to address two important aspects of decision-making: (a) setting priorities among hazards; and (b) considering options for controlling a particular hazard, such as the setting of an exposure limit. Given inevitable resource limitations, risk information is a valuable asset to decision-making.

Nevertheless, despite its scientific trappings, risk assessment is also a value-laden process. Its outcomes are heavily dependent on the models and methods chosen and the variables used in the calculations. Uncertainty is handled differently by different models, and the inputs selected influence the outputs. Options and decisions that flow from the process may make assumptions about "acceptable risk," which can vary among the many stakeholders affected by the policy or regulation. The values and assumptions underlying conclusions based on risk assessment may not be clearly articulated.

Risk assessment is generally distinguished from risk management and risk communication. There is a large and rich body of literature on all of these activities. Readers involved in communication and decision-making related to occupational safety and health are encouraged to acquaint themselves with these critical disciplines.

Control

The previously described tasks of occupational health practice—anticipating, recognizing, and evaluating hazards—produce information used to identify and assess workplace hazards and the circumstances that produce them. But prevention of work-related disease and injury requires action: selecting and implementing the strategies needed to eliminate or reduce hazardous workplace conditions. Decisions are guided by the knowledge generated by the previous steps, by professional experience and codes of practice, and by relevant statutory mandates and regulatory requirements. A host of prevention and control strategies are available, and the precautionary principle can help guide decisions in the face of uncertainty.

The Precautionary Principle

In public health, as in most other professions, it is usually necessary to take action based on imperfect or missing information. Research might produce answers or reduce uncertainty, but the scientific enterprise takes time and resources and thus could tolerate the very hazards we are committed to control. Often, decisions cannot wait. The basis for taking preventive actions is the "best available evidence"—the same legal requirement embodied in both the OSHAct and the Mine Act.

The precautionary principle embraces the fundamental precepts of public health; John Snow in the 1850s in London removed the handle from the

Broad Street pump without a full understanding of an epidemic of diarrheal illness and thereby interrupted a large outbreak of cholera. In recent years, this practice has been articulated more formally and proposed as a principle to guide public health policy for recognizing and controlling environmental health hazards. A consensus statement was developed in 1988 to address the following situation: "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause–and–effect relationships are not fully established scientifically." Four propositions were articulated:

(1) Preventive action should be taken even under conditions of uncertainty.
(2) The burden of proof should be shifted from having to prove an activity is harmful to having to prove that it is safe.
(3) A wide range of possible solutions should be considered.
(4) Everyone with an interest should be encouraged to participate in making decisions about what to do.

The precautionary principle tolerates uncertainty and elevates health and safety as the primary goal. Precautionary action is consistent with the "anticipation" aspect of the conventional formulation of the practice of industrial hygiene. Shifting the burden of proof also shifts the burden of uncertainty. It suggests erring on the side of caution.

The principle encourages consideration of a wide variety of solutions. This is consistent with a full understanding of the hierarchy of controls described below and the many types of interventions that can be employed in the workplace. In any particular situation, the workers, employers, and safety and health professionals involved can often identify a wide range of options for prevention and control. Solutions that appeal to common interests and are broadly understood are more likely to be supported and implemented. A wide base of participation in problem-solving that includes persons with a stake in the outcome will often result in better, more effective, and more efficient decisions.

Strategies for Action

Upon establishing the need for intervention—based on exposure levels, epidemiological or toxicological evidence, manifest cases of occupational disease or injury, and the occurrence of "near misses," and guided by the precautionary principle, it is necessary to design and implement specific hazard controls. In the work environment, primary prevention involves controlling the exposure or hazard at its source. This often requires engineering solutions, which employ basic methods of industrial hygiene and safety engineering. Other strategies, such as training, education, and administrative actions, can also be useful, especially when engineering interventions are not feasible or affordable. The following discussion briefly describes the essentials of industrial hygiene control methods for primary prevention. Detailed information about specific control methods can be found in textbooks and is also discussed in chapters in Part II.

Hazard Controls

In the workplace, primary prevention of disease and injury is largely an engineering problem, using basic concepts of industrial hygiene and injury prevention for the purpose of eliminating or controlling hazards. Below, we discuss methods of controlling health hazards and preventing disease; later, we discuss methods of controlling safety hazards and preventing injury.

Hierarchy of Controls

An elementary principle of reducing the risk of illness and injury from exposure to health hazards is that one reduces risk by reducing exposure. The most efficient way to reduce exposure is to eliminate the hazard altogether; this common sense concept is the foundation for a basic principle of industrial hygiene. There is a hierarchy of controls: The most efficient control is to eliminate the hazard by preventing its generation at the source. The next most efficient control is to prevent its dispersal into the environment with engineering controls. The least efficient control is to protect the individual worker with appropriate personal protective equipment. This translates into inherently safe production; environmental or engineering controls that prevent releasing hazards into the work environment and protect against unintended contact with hazardous equipment; or, least preferred, the use of personal protective equipment to protect each exposed worker.

Inherently safe production uses materials that are less toxic and methods that are less hazardous and whose safety features are an inseparable part of the process. This concept can and should be built into the design of machines or jobs just as are other features such as their efficiency or payload or the amount of power that is consumed. Inherently safe production methods are implemented best and most easily when new jobs or processes are being developed and before commitments are made that might have to be undone, sometimes at significant cost. In many instances, development of inherently safer methods will require research and development and will require a shift in perspective—from an emphasis on assessing and managing risks to an emphasis on developing inherently safer technological alternatives. This is the basis for emphasizing anticipation as a key ingredient in preventing occupational disease and injury.

The concept of inherently safe production may also be used to revise an existing job, process, or industry. The opportunity to devise safe production is not lost if the need becomes apparent only after hazards appear. Revisions in jobs are routine in industry, and inherently safe production methods should take their place alongside other revisions for other reasons. Given the opportunity and support, effective and efficient solutions can be developed with industrial hygienists, engineers, workers, and supervisors who are familiar with a particular job.

There are as many examples as there are work processes. Examples include substituting water for organic solvents in paints, glues, and parts-cleaning operations; substituting impact for pneumatic hammers; reducing the weight of manually handled objects (such as boxes or dry–wall panels); changing pay schedules to reduce incentives to cut corners; working at night to avoid heat stress; using non-silica materials, such as abrasive blasting agents; employing closed systems when using volatile chemicals; and isolating and controlling access to high-hazard operations.

Engineering controls and personal protective equipment are discussed below in relation to chemical and biological hazards and in relation to physical hazards. When chemical or biological hazards are released into the environment, workers may absorb them by any of several routes. Engineering controls and personal protective equipment prevent absorption by blocking these routes and, consequently, we organize the discussion below by the several potential routes of absorption.

Chemical and Biological Hazards

Airborne chemical hazards—gases, vapors, particulate matter, and microorganisms—are common. Inhalation is a frequent route of absorption. And ventilation is a frequent engineering control. Ventilation can control not only toxic substances but also oxygen deficiency, air temperature, and humidity. In general, there are two types of ventilation for hazard control: local exhaust and dilution. Local exhaust ventilation removes contaminated air from as close to its source as possible, removing it from the worker's breathing zone, cleaning it by means appropriate to the hazard (for example, dust particles may be removed by a filter and organic vapors with an absorbent material), and releasing it outside the workplace. In designing local exhaust ventilation systems, it is common practice to design controls that would enclose the source of the hazard completely and provide access as necessary for work and maintenance. This allows fewer opportunities for hazards to escape into the worker's breathing zone and reduces the need to remove and treat large quantities of air. There are standard designs of local exhaust systems for a wide variety of industrial processes, so practitioners need not redesign systems from first principles for each installation. (See the ACGIH *Industrial Ventilation Manual of Recommended Practice.*) Dilution ventilation is less efficient for controlling hazards and is used in circumstances when a hazard of relatively low toxicity is not released from discrete locations.

Control of infectious occupational diseases is based on standard methods of infectious disease control (see Heymann DL [Ed.]. *Control of Communicable*

Diseases Manual [18th ed.]. Washington, DC: APHA, 2004). Although exposures to some biological hazards are most common in the health care industry, they may also occur in agriculture, among emergency response workers, and in other industries and occupations. Indoor air quality of offices and schools may also be affected by bioaerosols (see Building-Related Illness).

Respirators appear to be a simple solution to protecting workers from airborne hazards and they do provide protection but not until several problems are addressed. Respirators leak. They make breathing more difficult (by both increasing the resistance to breathing and by increasing the physiological dead space (where air is inspired but no exchange occurs). They are uncomfortable. They interfere with communication and sometimes with vision. Some, especially air-supplied respirators, are burdensome. Some workers cannot wear respirators due to other medical problems, such as lung or heart disease or claustrophobia. And different hazards and different tasks require different kinds of respirators. Because of these problems, if respirators are used, they should be part of a respiratory protection program.

OSHA and MSHA both describe such programs (29 CFR 1910.134; 30 CFR 56.5005, 57.5005, 70D) based, in part, on a consensus standard developed by the American National Standards Institute (ANSI Z-88). These regulations and standards state that there are only two generic circumstances under which respirators may be used: (a) as temporary measures (during emergencies or while other controls are being implemented), or (b) when engineering controls are not feasible.

When respirators are used, they should be introduced with a respiratory protection program. This should include:

- hazard evaluation;
- task evaluation;
- selection of the appropriate respirator for the hazard;
- worker training and education about the hazard, its warning properties, and proper use and limitations of the respirator;
- fit-testing to prevent leakage;
- medical evaluation of workers to determine their ability to use respirators;
- monitoring of hazards and stress associated with the use of respirators;
- monitoring air quality for air-supplied respirators;
- maintenance and care of respirators; and
- proper storage and maintenance.

Certain tasks, such as strenuous work, needs to communicate, and work in close quarters, can be impaired by the use of the respirators and should therefore be evaluated. If the workplace is a confined space, additional precautions are needed to provide for emergency escape and rescue.

Communication among workers who have to wear respirators should be organized before work is begun in a hazardous environment.

Dermal absorption usually results from direct contact with liquids, although some vapors may be absorbed through the skin. Factors determining absorption are the concentration of the liquid at the surface of the skin, the surface area exposed, and the duration of exposure. Thus, dermal absorption can be eliminated or reduced by preventing contact, reducing the concentration of the chemical in contact with the skin, or reducing the surface area or duration of exposure.

Contact with chemical hazards usually results from specific work practices, housekeeping problems, or accidental spills. Each of these causes can be modified to reduce risk of exposure. Therefore, the work process itself should be evaluated to reduce the risk of contact and to change materials or work practices.

In some instances, gloves, aprons, or other forms of personal protective equipment are appropriate. However, different chemicals require different kinds of barrier fabric to be effective. Selection is facilitated by use of the *NIOSH Pocket Guide to Chemical Hazards*.

Ingestion of hazards may occur if food, drink, or smoking materials become contaminated, if workers place contaminated fingers or implements into their mouths, or if splashes occur. Chemical hazards may also be ingested secondary to inhalation, coughing, and swallowing; preventing ingestion by this route is the same as preventing inhalation. Otherwise, preventing ingestion requires, for example, preventing eating, drinking, or smoking in areas where contamination might occur and by providing a clean place to eat and facilities (and time) for workers to clean up before eating.

Other routes of exposure to chemical or biological hazards are by injection (by hypodermic needles or paint guns) or by transplacental transport. Preventing exposure by these routes requires more specialized means.

Physical Hazards

Noise, ionizing and nonionizing radiation, and radiant heat are all forms of radiant energy and because of this similarity, exposure can be controlled with certain generic means. Risk of injury from these hazards is proportional to the amount of energy generated, released, and absorbed. Thus, one can reduce the risk of injury by:

- reducing the amount of energy generated or released,
- shielding or enclosing the source or the worker (in a cab or booth),
- increasing the worker's distance from the source,
- reducing the duration of exposure, or
- providing the worker with personal protective equipment.

Shielding the source is possible because radiant energy can be reflected or absorbed with appropriate shielding material. Increasing the distance between the worker and the source is useful because radiant energy attenuates by the inverse square rule (its intensity declines with the inverse square of the distance from the source). Reducing the time of exposure is useful because harmful effects are proportional to the duration of exposure. For more detail, see Part II chapters on Hearing Loss, Noise-Induced; Radiation, Ionizing and Nonionizing; and Heat Stress.

Evaluation and control of exposure to ionizing radiation is complex, and readers are advised to consult references listed in the chapter on this subject in Part II. Energy emitted from lasers, a unique form of radiant energy, is monochromatic, synchronized, and highly focused; consequently, it does not follow the inverse square rule. The risk of injury from a laser beam depends on the strength of the beam and the probability of intercepting the beam itself.

Vibration is mechanical energy transmitted directly to a worker's body by vibrating tools or machines or vehicles. Depending on its frequency and where on the body it is transmitted, vibration can affect limbs, organs, or the whole body. It is best controlled by eliminating the source, such as by using impact as opposed to pneumatic hammers or by isolating the worker from the source. Low-frequency whole-body vibration, such as from moving vehicles, can be controlled by ensuring proper vehicle suspension, maintaining smooth roadways, and providing adequate seats (see Hand-Arm Vibration Syndrome and Low–Back Pain Syndrome in Part II).

Personal protective equipment to protect workers from physical hazards depends on the nature of the hazard. Thus, hearing protection (ear muffs or plugs) may be needed to protect workers from noise, eye shades to protect from ultraviolet (UV) radiation or flying objects, and reflective clothing to protect against radiant heat. In each case, however, these forms of personal protective equipment come with their own problems. Hearing protection masks other important sounds (such as back-up alarms and noise of oncoming equipment), interferes with communication, and is often uncomfortable. (For more details and for a discussion of a comprehensive hearing conservation program, see the Part II chapter on Hearing Loss, Noise-Induced.) Protective clothing may protect workers, but it also may be burdensome and may increase heat stress.

Ergonomic Hazards

As discussed in the chapters on Musculoskeletal Disorders, Carpal Tunnel Syndrome, Tendonitis and Tenosynovitis, and Low Back Pain Syndrome, controlling the hazard through engineering controls (substituting mechanical for physical energy) is not only the preferred method, but may be the only effective preventive measure. In some instances, personal protective equipment, such as splints and back belts, has been used for primary or secondary prevention, but with little effect. Administrative controls, such as work breaks for keyboard operators and others engaged in highly repetitive tasks, have also been used.

Ongoing Monitoring

Workplaces and the people who work in specific workplaces change over time. Materials used in the production process change. Work processes are modified. Workers and managers change jobs. Some workplaces, such as most construction worksites, are dynamic. In others, change comes more slowly. Therefore, an effective and comprehensive program for prevention of occupational disease and injury requires ongoing monitoring of hazards and health in order to assure the adequacy of controls in place and prevention strategies in use, and to assist in the recognition of new problems before they become widespread. The intensity of the monitoring should be proportionate to the level of risk and the stability of the work process. Workplace hazard surveillance and worker health surveillance, along with periodic updating of a comprehensive hazard inventory, are useful approaches for ongoing monitoring.

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