Chapter 10

Industrial Hygiene

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Industrial hygiene is the health profession devoted to the recognition, evaluation, and control of environmental hazards. Environmental hazards include chemical hazards, physical hazards, biologic hazards, and ergonomic factors that cause or contribute to injury, disease, impaired function, or discomfort. Industrial hygiene is thus a major component of primary prevention programs for occupational and environmental diseases.

Historical developments in industrial hygiene and industrial medicine are closely intertwined. Industrial hygiene principles have evolved over many years, with extensive development during the Industrial Revolution. Ancient Roman slaves working in mercury mines recognized the presence of a hazard and devised bladder skin masks in an attempt at avoiding toxic fumes. Writings of Pliny the Elder (C. 23–79 AD) provide the earliest record of protective masks for miners. Georgius Agricola (1494–1555), in his book *De Re Metallica*, further describes working conditions and illness among metal miners. Agricola recommended the use of protective equipment such as "boots of rawhide, but gloves long enough to reach to the elbow, and they should fasten loose veils over their faces." Mine ventilation, using "bellows which draw up these noxious vapors," also was described by Agricola. Bernardino Ramazzini (1633–1714) is generally regarded as the father of occupational medicine. His classic 1700 publication *De Morbis Artificum Diatriba* provides a comprehensive review of diseases and preventive measures for a large number of industries and occupations. Many Western European countries incorporated principles of hygiene into law in the 19th Century. In the United States, an Office of Industrial Hygiene and Sanitation was created within the Public Health Service in 1914.

Industrial hygienists share responsibilities with physicians for identification of adverse health conditions of possible environmental origin. Industrial hygienists provide information concerning industrial processes, potential exposures, and measured exposure levels that can be used to establish a probable causal link with a worker's adverse health condition. Industrial hygienists apply engineering controls, improved work practices, and protective equipment to reduce or eliminate occupational exposures and the adverse health conditions associated with these exposures.

In addition to their traditional roles in the recognition, evaluation, and elimination of current occupational hazards, industrial hygienists play a vital role in exposure assessment for epidemiologic investigations and medicolegal case reviews. Many environmental exposures result in chronic diseases many years after the initial exposure. Industrial hygienists use knowledge of industrial processes, controls, and exposure measurements, in conjunction with detailed occupational histories, in order to reconstruct exposures and potential exposures for individuals. Combined with the task of direct measurement of evident exposures, industrial hygienists contribute importantly to our database of the causal effects of exposures and exposure-response relationships.

Industrial hygiene involves integration of knowledge from several scientific disciplines, including engineering, chemistry, physical science, toxicology, and medicine. Industrial hygienists are usually trained in one of these disciplines, and their graduate study is grounded specifically in industrial hygiene or a closely related field. In the United States, industrial hygienists are certified through work experience and a written comprehensive examination administered by the American Board of Industrial Hygiene.

INDUSTRIAL HYGIENE AND DISEASE PREVENTION

Prevention of environmental diseases may be thought of as a two-stage process involving primary prevention and secondary prevention. The ultimate objectives are (1) to prevent the occurrence of disease, (2) to reduce the likelihood of disease recurrence or progression, and (3) to ameliorate the morbidity associated with the disease. Prevention of environmental diseases involves *hazard recognition, hazard evaluation,* and *hazard control and intervention.*

Hazard Recognition

The hazard associated with a given exposure is a function of both the toxicity of a material and the likelihood of human exposure. Health data may be generated through environmental and occupational medicine and surveillance programs or through epidemiologic studies. Toxicology often provides valuable information with regard to hazard recognition.

Hazard Evaluation

Hazard evaluation involves a series of steps aimed at establishing the degree of hazard associated with a particular exposure or work condition. Hazard evaluations are essential for determination of the need for additional control measures

to minimize exposures and as possible clues to the cause of an adverse health condition observed in a worker or group of workers. Hazard evaluation requires knowledge and information relative to

1. Industrial processes and jobs and potential exposures to contaminants.
2. Properties of contaminants and potential routes of human exposure.
3. The actual magnitude and frequency of worker exposures to a contaminant. In the absence of quantitative exposure information, estimates of the *potential* for human exposure often are useful for hazard identification.
4. Potential adverse health effects resulting from an exposure and the approximate level of exposure at which adverse effects occur.

Hazard Control and Intervention

Primary prevention involves application of methods to reduce or eliminate human exposures. Principles and methods for controlling occupational hazards are discussed more fully later in this chapter.

RECOGNITION OF OCCUPATIONAL AND ENVIRONMENTAL HAZARDS

Classification of Hazards

Workers may be exposed to contaminants by inhalation, absorption through the skin, ingestion, or injection (e.g., through accidental puncture wounds). Inhalation and skin absorption represent the predominant routes of exposure for most materials in the occupational environment. Ingestion may an important source of exposure in areas where poor hygiene practices, such as consumption of food and beverages in the contaminated work areas, are allowed. Ingestion also may be a very important route for nonoccupational toxin exposures.

Environmental agents are broadly classified by the Occupational Safety and Health Administration (OSHA) in the Hazard Communication Standard as either physical hazards or health hazards.

Physical Hazards. Materials such as explosives, flammable or combustible liquids, oxidizers, compressed gases, organic peroxides, pyrophoric materials, unstable (reactive) chemicals, and water-reactive chemicals are regarded as physical hazards by OSHA. Other exposures in the workplace, such as excessive noise, ionizing and nonionizing radiation, and temperature extremes, are other examples of physical hazards.

Ergonomic factors are becoming increasingly important causes of injury in the workplace. Repetitive motions, often in awkward positions, are responsible for a number of chronic trauma disorders such as carpal tunnel syndrome.

Health Hazards. Health hazards include both chemicals and biologic materials that are capable of producing adverse acute or chronic health effects. Chemical hazards include exposures to chemical mists, vapors, gases, and particulates (dusts and fumes) through inhalation or by absorption through the skin. Hazardous chemicals include carcinogens, reproductive toxins, irritants, corrosives, sensitizers, hepatotoxins, nephrotoxins, agents that act on the hematopoietic system, and agents that damage the lungs, skin, eyes, or mucous membranes. Certain biologic materials also may be health hazards. Biologic hazards include exposures to infectious or immunologically active agents such as molds, fungi, and bacteria.

Types of Airborne Contaminants

Aerosols. Aerosols are composed of liquid droplets or solid particles that are fine enough to remain dispersed in air for a prolonged period of time. Aerosols also may be referred to as airborne particulate matter. Typical size ranges for aerosols are shown in Figure 1.

DUSTS. Dusts are solid particles suspended in a gaseous media. Dusts result from the mechanical disintegration of materials, such as grinding, with enough mechanical energy to propel particles into the air. Airborne dust particles vary widely in size from approximately 50 μm to less than 1 μm. Only the larger particles may be seen without the use of a microscope. Most industrial dusts consist of particles that vary widely in size, with the small particles greatly outnumbering the large ones. In general, when dust is noticeable in the air near an industrial operation, exposures to large numbers of smaller particles can be anticipated.

Airborne dusts show wide variability in particle shape. Figure 2 shows typical dusts from a rubber processing operation using industrial talc. The particles are flat to rounded and compact. In comparison, Figure 3 shows a microscopic photograph of dusts contaminated with asbestos from a talc mine. This photograph demonstrates greatly elongated asbestos fibers.

FUMES. Fumes are formed when the material from a volatilized (evaporated or vaporized) solid condenses in cool air. The solid particles that are formed are extremely small, usually less than 1.0 μm in diameter. In most cases, the freshly generated fumes react with the oxygen in the air to form an oxide. Welding, metalizing, and other operations involving heating of metals to high temperatures produce vapors from the molten metal that quickly become fumes. Arc welding converts metal to a vapor that condenses, usually as the metal or its oxide. Fumes, because they are extremely fine, are readily inhaled.

SMOKE. Smoke is usually produced by the incomplete burning of carbonaceous materials such as coal and oil. The resulting aerosol consists of carbon or soot particles less than 0.1 μm in size. Smoke, such as tobacco smoke, generally contains droplets as well as dry particles.

MISTS. Mists are finely divided liquid droplets that are airborne. Mists may be generated by the condensation of liquids from the vapor back to the liquid state or by breaking up a liquid into a dispersed state, such as by splashing, foaming, or atomizing. In industrial operations, mists are produced during paint spraying, during spray application of pesticides

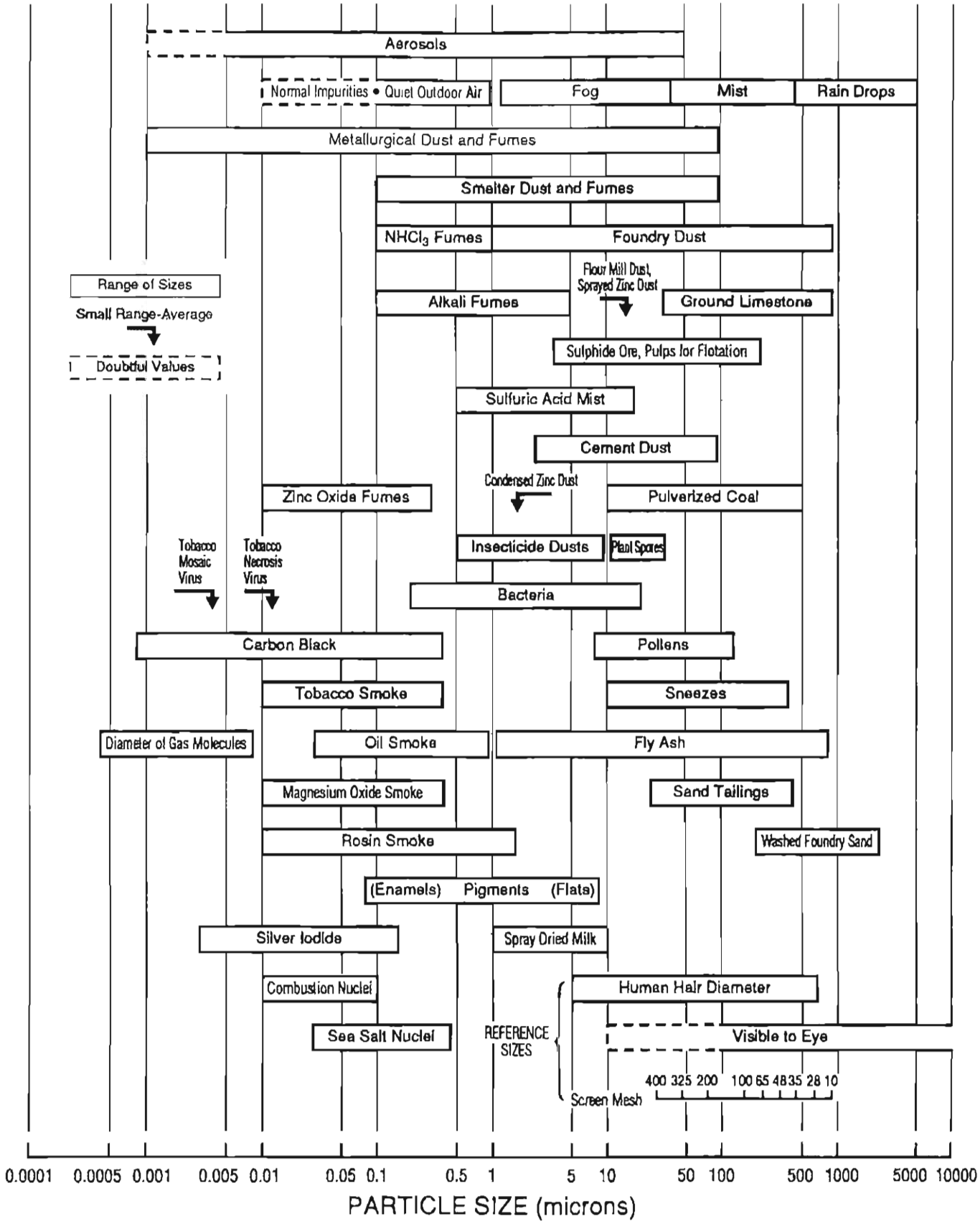

FIGURE 1 Size ranges for airborne contaminants, and comparisons with reference sizes.

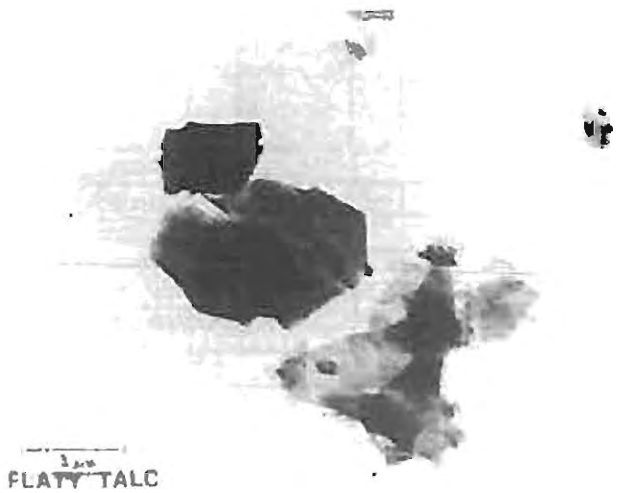

FIGURE 2 Electron microscope image of airborne particles from an industrial rubber operation using nonfibrous talc.

and herbicides, and during cutting and grinding operations. Acid mists are produced during metallurgic pickling operations and during electroplating.

PARTICLE RESPIRATORY DEPOSITION. The hazard associated with airborne particulate matter is a function of (1) the biologic activity of the material, (2) the concentration of the airborne material, and (3) the size of the airborne particle. Particle size determines the site of deposition within the respiratory system. Many occupational diseases, such as silicosis and asbestosis, are associated with material deposited in different regions of the respiratory tract. Criteria have been developed to define critical size-fractions most closely associated with various health effects. The various critical fractions are shown in Figure 4 and are defined as follows:

Inspirable Fraction—This is the fraction of airborne particulate matter that can be deposited in either the upper or lower respiratory tract.

Thoracic Fraction—These are particles that are deposited in the lower respiratory tract, including airways or the lung parenchyma (terminal bronchi and alveoli).

Respirable Fraction—These are particles that are deposited in the lung parenchyma.

FIGURE 3 Electron microscope images of airborne particles from a talc mine and a mill processing talcs contaminated with asbestiform minerals (seen as long, thin fibers).

Gases. Gases are formless fluids that expand to occupy the space or enclosure in which they are confined. The gaseous state is normally restricted to temperatures and pressures that would normally be present in the ambient or occupational environments.

VAPORS. Vapors are the gaseous form of substances that are normally in the solid or liquid state at room temperature and pressure. Evaporation is the process by which a liquid is changed into the vaporous state and mixed with the surrounding atmosphere. Many solvents convert into vapors at normal temperatures and pressures. In addition, the application of heat in many industrial operations produces more vapor.

Fire and Explosion Hazards

Under appropriate conditions, gases, vapors, and dusts present fire and explosion hazards. Fires and explosions account for a large majority of catastrophic industrial accidents that result in injury and death. The following are key definitions and concepts:

Flash Point—The flash point is the lowest temperature of a liquid at which vapor is given off in sufficient quantities that the vapor or air mixture above the surface will propagate (spread) a flame away from the source of ignition through the vapor or air mixture. A vapor or air mixture whose concentration is below the lower limit of flammability may burn in the zone immediately surrounding the source of ignition, without spreading away from the source ignition.

The flash point is an important concept with regard to fire hazard recognition. If a liquid has no flash point, it is not flammable or combustible and, conversely, the presence of a flash point indicates flammability or combustibility. It must be emphasized, however, that finely divided liquids, such as a mist or a spray, can be ignited at temperatures below their flash points.

Flammable (Explosive) Limits—Vapors of a flammable or combustible liquid must be mixed with air in the proper proportions, in the presence of a source of ignition, for combustion or an explosion to occur. The proper mixture with air is called the flammable range, which also may referred to as the explosive range. The flammable range includes all concentrations of flammable vapor or gas in air, in which a flash will occur or a flame will travel if the mixture is ignited. The minimum concentration of vapor or gas in air below

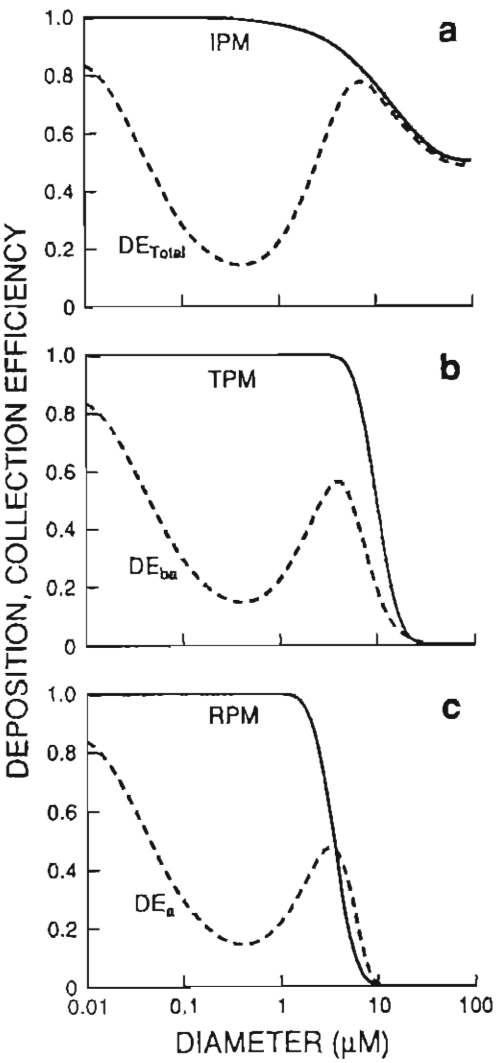

FIGURE 4 ACGIH reference curves for inspirable *(A)*, thoracic *(B)*, and respirable *(C)* fractions of airborne particulates. In *(A)*, total inspirable fraction, or IPM, demonstrates that most particles under 100 μm are *inspirable.* The DE_{total} curve reflects the fact that all but particles between 0.1 and 1.0 μm are well retained in the respiratory tract. In *(B)*, it is apparent that particles under 10 μm are able to enter the bronchial tree and are called *thoracic*, or TPM. DE_{ba} shows the proportion of particles of each size deposited in the bronchoalveolar compartments. Particles of smaller size (<5 μm) are *respirable*, labeled RPM in *(C)*. Alveolar deposition is indicated by the DE_a curve.

which propagation of flame does not occur on contact with a source of ignition is called the lower flammable or explosive limit (LEL). The maximum concentration of vapor in air above which propagation of flame does not occur is called the upper flammable or explosive limit (UEL). A vapor or air mixture below the lower flammable limit is too lean to burn or explode, and a mixture above the upper flammable limit too rich to burn or explode.

Ignition Temperature—The minimum temperature required to initiate or cause self-sustained combustion independently of the heating or heated element is called the ignition temperature. Ignition temperatures may be changed substantially by a change of conditions. Percentage composition of the vapor or gas-air mixture, shape and size of the space where the ignition occurs, rate and duration of heating, kind and temperature of the ignition source, catalytic or other effect of materials that may be present, and the oxygen concentration may change ignition temperatures.

Flammable Liquids—The National Fire Protection Association, Flammable and Combustible Liquids Code, Standard Number 30, defines a flammable liquid as any liquid having a flash point below 100° F (37.8° C) and having a vapor pressure (see later) not exceeding 40 psia at 100° F.

Combustible Liquids—Combustible liquids are those with flash points at or above 100° F. Combustible liquids do not ignite as easily as flammable liquids, although they can be ignited under certain circumstances.

Explosive Dusts—Any industrial dusts may be explosive when airborne. Notable examples are finely divided particles of aluminum and magnesium. Many airborne organic dusts are explosive. Fires and explosions occur readily in grain elevators; woodworking plants; feed, cereal, flour, and paper mills; and fertilizer plants. The particle size of the dust particles and the density of the dust cloud produced are factors that govern the potential fire and explosion hazards.

Many materials are themselves capable of detonation or of explosively decomposing, some may be sensitive to mechanical or local thermal shock, and some may react only at high temperatures. Some materials need to be only slightly contaminated to produce a violent reaction. Materials, such as peroxides, perchlorates, fluorine, and chlorine, support combustion directly or by evolution of oxidizers.

Boiling Point—The boiling point of a liquid is the temperature at which the liquid's vapor pressure is equal to the gas pressure at its surface. The boiling point thus is highly dependent on the gas pressure above the liquid. Liquids such as solvents evaporate to form vapor at lower temperatures. As the temperature of an organic liquid increases, vapor formation occurs more rapidly. Liquids with low boiling points have relatively a high vapor pressure at room temperature and convert into gases readily, whereas those with high boiling points convert more slowly.

Vapor Pressure—When a liquid of a substance is exposed to the atmosphere, there is a continuous movement of molecules from the liquid into the atmosphere. The vapor pressure of a substance is the pressure, at any given temperature, of the vapor or the substance in equilibrium with its liquid or solid form. The vapor pressure of a solvent is an important parameter to be considered when estimating fire and inhalation hazards. The vapor pressure determines the tendency of a substance to become airborne and pose a hazard through inhalation. Organic liquids with high vapor pressures are potentially hazardous because they evaporate readily into the air to produce high vapor concentrations. Substances with low vapor pressures at temperatures of their use do not vaporize readily and are an inhalation risk only if they turn into a mist or spray.

Measures of Airborne Concentration

Airborne concentrations of contaminants are expressed in several ways depending on the form of the contaminant and the sampling and analysis method used to measure the air-

borne concentration. Terms used to describe degree of exposure are

ppm—Parts of vapor or gases per million parts of contaminated air by volume at room temperature and pressure.

mppcf—Millions of particles of a particulate per cubic foot of air.

mg/m^3—Milligrams of a substance per cubic meter of air.

Vapor %—Parts of vapor or gas per 100 parts of contaminated air by volume at room temperature and pressure

Fibers/cc—A measure of the numbers of fibers longer than 5 μm in length per cubic centimeter of air. This measure is used for asbestos and human-made fibers.

Occupational Exposure Standards and Guidelines

TWA (Time-Weighted Average)—A method of calculating a daily or full-shift average exposure by weighing the different short-term average concentrations by exposure time.

$$TWA = \frac{C_1T_1 + C_2T_2 + \ldots C_nT_n}{T_1 + T_2 + \ldots T_n}$$

Where C_1 equals concentration of contaminant measure during the time period, T_1 equals time for average concentration C_1.

REL (NIOSH Recommended Exposure Limit)—RELs are generally time-weighed average concentrations for up to a 10-hour workday during a 40-hour work week.

STEL (Short-term Exposure Limit)—A STEL is normally a 15-minute (or other specified time period) TWA that should not be exceeded during any time of the workday.

PEL (OSHA Permissible Exposure Limit)—PELs are usually TWAs that must not be exceeded during any 8-hour work shift of a 40-hour work week.

Ceiling Concentration—Maximum OSHA concentration that must not be exceeded during any part of the workday.

TLV (Threshold Limit Values)—Nonregulatory exposure recommendations by the American Conference of Governmental Industrial Hygienists (ACGIH). These are usually 8-hour TWA concentrations. STELS are recommended by the ACGIH for some compounds.

General Principles of Industrial Hazard Recognition

Hazard recognition involves a systematic review of a worker's occupational environment to identify exposures and potential exposures. This review should provide the following types of information:

- Materials produced or stored and the process involved.
- Raw materials that are used or added to the process.
- Byproducts formed during the production process.
- Types of industrial equipment used.
- Cycle of operation or frequency of exposure, or both.
- Operational methods and work practices used.
- Health and safety controls used in workplace.
- Use of personal protective equipment.
- Frequency and duration of worker exposure.
- Number of workers exposed.

Although the most useful data for hazard identification are the magnitude and frequency of exposure, such data are rarely available for all contaminants of interest. The health professional is then faced with estimating the *potential for exposure* using other surrogate data sources. Information concerning plant processes, hazardous raw materials and byproducts, work practices, types of control measures, use of protective equipment, and duration of exposure often can be obtained from plant personnel or through occupational histories.

The OSHA hazard communication standard provides a valuable information resource for hazard identification. This standard requires employers to (1) develop a written hazard communication program, (2) maintain a list of all hazardous chemicals in the workplace, (3) make available to workers Material Safety Data Sheets (MSDSs) for each hazardous chemical, (4) place labels on containers of chemicals as to their identity and precautions in handling, and (5) to provide workers with education and training in the handling of hazardous chemicals.

An MSDS is a short document (several pages) that provides a summary of information concerning a hazardous material. The OSHA hazard communication standard does not require a standard format for MSDSs; however, the types of information that must be provided are specified. Figure 5 is a nonmandatory MSDS format suggested by OSHA. The following is a summary of information to be provided by an MSDS:

Section I: Contains general information, such as (a) chemical identity, (b) manufacturer's name and address, and (c) emergency telephone numbers.

Section II: Lists the hazardous ingredients and identifying information. Includes any synonyms, TLVs, or recommended occupational exposure limits.

Section III: Lists the physical and chemical characteristics that are applicable. Can include boiling point, vapor pressure, vapor density, specific gravity, melting point, evaporation rate, and appearance and odor.

Section IV: Contains fire and explosion hazard data. This section includes flash point, flammable limits, extinguishing media, special fire fighting procedures, and any unusual hazards.

Section V: Contains reactivity data. States conditions of stability, any incompatibilities, hazardous decomposition products, and hazardous polymerization conditions.

Section VI: This section lists those health hazards that may arise from acute or chronic exposure, the route of entry, target organ, signs and symptoms of exposure, emergency first aid procedures, and whether the chemical is classified as a carcinogen.

Section VII: Lists the precautions for safe handling and use. Included are steps to be followed in case of a spill, waste disposal methods, and handling or storage precautions.

Section VIII: Contains control measures that are to be followed when the chemical in question is used. This includes what type of respiratory protection is required, ventilation requirements, other personal protection devices and clothing, and specific work practices.

Although MSDSs are valuable for hazard identification, they must be used with a degree of caution for several reasons. First, quality and completeness varies considerably among chemical producers. Second, the OSHA standard does not require chemical producers to conduct further toxicologic studies to define the hazard of a chemical—the standard

requires only the disclosure of a known hazard. Thus, the quality of an MSDS depends greatly on published literature concerning the hazard of a substance.

In addition to information concerning raw materials used and byproducts formed, information concerning the type of industrial process and jobs performed by workers often is helpful in hazard identification. In most industrial processes, several hazards are present. Industrial hygienists have training and experience in identifying process-specific and job-specific hazards. Table 1 provides a brief summary of typical plant processes and the types of hazards that may be present. In addition, the National Institute for Occupational Safety and Health (NIOSH) has conducted several national surveys to identify potential exposures and hazards by industry and job. Data from these surveys often are helpful in identifying potential occupational exposures when a worker's job title and industry of employment are known but details about specific risks cannot be ascertained.

In considering possible exposures to workers, it is important to consider exposures that occur during nonroutine tasks such as maintenance and cleaning. Maintenance workers may be exposed to most chemical hazards in the plant environment in addition to other materials such as asbestos, man-made mineral fibers from insulation materials, cutting oils, and lubricants. Cleaning operations, especially using dry sweeping, may resuspend materials, creating a significant potential for particulate exposures.

SOURCES THAT DELINEATE OCCUPATIONAL EXPOSURE LIMITS AND PROVIDE HAZARD INFORMATION

OSHA Air Contaminant Standards

The goal of the Occupational Safety and Health Act of 1970 is "to assure so far as possible every working man and woman in the Nation safe and healthful working conditions." In order to achieve this goal, the Act authorizes the Secretary of Labor to issue occupational health and safety standards. In the case of air contaminants, the Act requires that these standards be set as exposure limits "which most adequately assure(s), to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life. . . .". In accordance with this mandate, in 1971, OSHA promulgated approximately 425 PELs for air contaminants, derived principally from the ACGIH-TLVs of 1968.

The Act also describes mechanisms for updating these standards, which include the requirements that OSHA must provide notice of proposed rule making, give interested parties an opportunity to comment, and hold a public hearing if requested. As of 1988, OSHA had issued only 24 substance-specific and three "generic" health standards under these provisions. In 1988, OSHA published a Notice of Proposed Rulemaking for its Air Contaminants Standard. In order to update and expand the PELs, OSHA proposed to issue new or revised PELs for over 400 substances using the ACGIH-TLVs and the NIOSH-RELs as the starting point for updating the standards. After a public comment period, OSHA analyzed the information and issued its revised Air Contaminants Standard for 428 toxic substances in January 1989. This updated standard lowered the PELs for 212 substances and set new PELs for 164 previously unregulated substances. The standard specified a 4-year period for employers to come into compliance with the new standard using engineering and work practice controls. Until that time, employers may use respirators or any other reasonable methods to comply with the standards. However, this standard was vacated by a legal challenge in 1992. OSHA continues to encourage employees to follow the updated PELs, although only the old (pre-1989) PELs are legally enforceable at this time. OSHA may issue Emergency Temporary Standards under section 6(c) of the Act when it determines "that employees are exposed to grave danger from exposure" to toxic substances. Once OSHA has published an emergency standard, proceedings must commence for issuance of a regular standard under section 6(b).

OSHA also has regulations pertaining to access to medical and exposure records. Under these regulations (29 CFR 1910.20), health professionals may obtain access to medical records and exposure information from employers and former employers. The OSHA Hazard Communication Standard 29 CFR 1910.1200 (see earlier) mandates that employers inform employees of potentially hazardous materials. The regulation specifies requirements for the labeling and communication of information on the hazardous properties of chemicals. It applies to chemical manufacturers, importers, and distributors. The standard includes a basic list of substances that must be treated as hazardous, and the term hazardous chemical is defined as any chemical that is a physical hazard or a health hazard.

NIOSH Recommendations

NIOSH develops and recommends criteria for preventing disease and hazardous conditions in the workplace. These recommendations are issued in several forms, including RELs published as criteria documents and current intelligence bulletins. Information on recommended methods for prevention, including engineering controls, guidelines for selecting personal protective equipment such as respirators, and safe work practices are published in documents such as hazard alerts and occupational hazard assessments.

The NIOSH recommendations are not legally enforceable in themselves; however, they are transmitted to OSHA and the Mine Safety and Health Administration (MSHA) for use in promulgating legal standards. NIOSH has recommended exposure limits for approximately 550 chemicals and compounds, as well as for physical hazards, including hand-arm vibration, heat, noise, radon progeny, and ultraviolet radiation. Safety and health standards also have been recommended for industries, processes, and work environments including foundries, confined spaces, and logging operations.

Toxicologic Reviews

Reviews and evaluations of information on the toxicity of hazardous substances are prepared by several governmental and private organizations in the United States and internationally. The Agency for Toxic Substances and Disease Registries (ATSDR) of the United States Department of Health and Human Services prepares toxicologic profiles for compounds that are commonly found at hazardous waste sites

Material Safety Data Sheet

May be used to comply with
OSHA's Hazard Communication Standard,
29 CFR 1910.1200. Standard must be
consulted for specific requirements.

U.S. Department of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

IDENTITY *(As Used on Label and List)*	*Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.*

Section I

Manufacturer's Name	Emergency Telephone Number
Address *(Number, Street, City, State, and ZIP Code)*	Telephone Number for Information
	Date Prepared
	Signature of Preparer *(optional)*

Section II — Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity; Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended	% *(optional)*

Section III — Physical/Chemical Characteristics

Boiling Point		Specific Gravity (H_2O = 1)	
Vapor Pressure (mm Hg.)		Melting Point	
Vapor Density (AIR = 1)		Evaporation Rate (Butyl Acetate = 1)	

Solubility in Water

Appearance and Odor

Section IV — Fire and Explosion Hazard Data

Flash Point (Method Used)	Flammable Limits	LEL	UEL

Extinguishing Media

Special Fire Fighting Procedures

Unusual Fire and Explosion Hazards

(Reproduce locally) OSHA 174, Sept. 1985

FIGURE 5 OSHA-suggested format for material safety data sheet, or MSDS. Although required in the United States under the Hazard Communication Standard, many different formats are used by different companies.

Section V — Reactivity Data

Stability	Unstable		Conditions to Avoid
	Stable		

Incompatibility (*Materials to Avoid*)

Hazardous Decomposition or Byproducts

Hazardous Polymerization	May Occur		Conditions to Avoid
	Will Not Occur		

Section VI — Health Hazard Data

Route(s) of Entry: Inhalation? Skin? Ingestion?

Health Hazards (*Acute and Chronic*)

Carcinogenicity: NTP? IARC Monographs? OSHA Regulated?

Signs and Symptoms of Exposure

Medical Conditions
Generally Aggravated by Exposure

Emergency and First Aid Procedures

Section VII — Precautions for Safe Handling and Use

Steps to Be Taken in Case Material Is Released or Spilled

Waste Disposal Method

Precautions to Be Taken in Handling and Storing

Other Precautions

Section VIII — Control Measures

Respiratory Protection (*Specify Type*)

Ventilation	Local Exhaust	Special
	Mechanical (*General*)	Other

Protective Gloves	Eye Protection

Other Protective Clothing or Equipment

Work/Hygienic Practices

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* U.S.G.P.O. 1986-491-529/45773

FIGURE 5 *Continued*

TABLE 1 Industrial Processes and Associated Hazards

Process or operation	Nature and description of hazards
Abrasive blasting	Abrasive blasting equipment may be automatic or manually operated. Either type may use sand (free silica), steel shot, or artificial abrasives. Excessive noise or vibration may occur
Assembly operations	Improper positioning of equipment and handling of work parts present ergonomic hazards
Babbitting	Fumes and dusts of oxides of antimony, lead, tin, and zinc are generated
Bagging and handling of dry materials	Conveying, sifting, sieving, screening, packaging, or bagging of any dry material may present a dust hazard. Inhalation and skin contact hazards may be present
Ceramic coating	Airborne dispersion of toxic pigments and metal oxides plus hazards of heat stress from the furnaces and hot ware may occur
Coal handling	Dusts and gases of carbon monoxide, coal, free silica, and sulfur dioxide are present
Coke handling	Coke and free silica dust may be inhaled
Coking	Contaminants encountered include ammonia, benzene, carbon disulfide, carbon monoxide, cyanamides, hydrogen sulfide, naphthalene and other popycyclics, phenols, pyridine, and sulfur dioxide
Dry grinding	Dry grinding operations may produce airborne dusts and ergonomic hazards
Dry mixing	Mixing of dry matrial may present a dust hazard
Electro-tinning (alkaline and halogen)	Mists of caustics, chromates, fluorides, and sulfuric acid occur
Electron beam welding	Electric discharge in a vacuum may be a source of ionizing radiation
Fabric and paper coating	The coating and impregnating of fabric and paper with plastic or rubber solutions may involve evaporation of large quantities of solvents
Forming and forging	Hot bending, forming, or cutting of metals or nonmetals may cause exposures to lubricant mist, decomposition products of the lubricant, skin contact with the lubricant, heat stress (including radiant heat), noise, and dust
Furnace operations	Dusts, fumes, and carbon monoxide, iron oxide, metal oxides, sulfur dioxide and other combustion products occur
Galvanizing	Entails exposure to fumes, gases and mists of ammonium chloride, chromates, hydrochloric acid, hydrogen chloride, lead oxides, and zinc oxide
Gas furnace or oven heating	Products of combustion may be released. Burner noise may be excessive.
Grinding	Grinding, crushing, or comminuting of any material may generate dust of the material being processed or the grinding wheel abrasive itself (see dry grinding and wet grinding)
Leaded steel making	Dusts and fumes of iron oxide and lead oxide
Maintenance operations	Exposure to typical hazardous materials in the process plus asbestos, manmade mineral fibers, cutting oils, and lubricants. Cutting and welding hazards and frequent solvent exposures
Materials handling, warehousing	Carbon monoxide and oxides of nitrogen arising from internal combustion engine forklift operations. Secondary spills may resuspend dusts
Metalizing	A high-temperature coating of parts (spraying) with molten metals presents exposure to dust and fumes of metals and their oxides, fluxes, and carbon monoxide in addition to heat and nonionizing radiation
Microwave and radiofrequency	Microwave heating operations or induction heating may produce heating effects, electromagnetic field exposures, and noise exposures
Molten metals	Melting and pouring of molten metals may produce toxic gas, metal fume, and dust. Acrolein often is produced
Ore handling	Dusts of fluorides, free silica, and iron oxide. Some ores may contain other toxic metals as well as mineral fibers
Paint spraying	Paint spraying operations produce hazards from inhalation and skin contact with toxic and irritating solvents, toxic pigments (cadmium, chromates, lead), or resins (epoxies, polyurethanes). The solvent vapor evaporating from the sprayed surface also may be source of hazard
Pickling (steel)	Gases and mists of hydrochloric acid, hydrogen chloride, hydrogen fluoride, oxides of nitrogen, and sulfuric acid occur
Plating	Associated with skin contact with strong chemicals and a respiratory hazard if mist or gases from the plating solutions are dispersed. Most commonly, these can be acids, alkalis, and chromic acid mist
Punch press, press brake, drawing	Cold bending, forming, or cutting of metals or nonmetals may involve hazards of contact with lubricant, inhalation of lubricant mist, and excessive noise
Refractories handling	Free silica dust occurs as well as asbestos fibers
Sintering	Dusts and gases of carbon monoxide, fluorides, free silica, metal oxides, and sulfur dioxide
Solvent degreasing	Vapors of perchloroethylene, trichloroethylene, vapor decomposition products (e.g., phosgene), and other solvents
Steelmaking (material handling)	Dusts of fluorspar, graphite, iron oxide, limestone, and ore may be inhaled
Tandem rolling mills	Oil mist is a dermal and inhalation hazard
Vapor degreasing	The removal of oil and grease from metal products may present hazards from solvents
Welding, gas or electric-arc (brazing)	Processes involving the melting and joining of metal parts may produce exposures to fumes and gases. Oxides of cadmium, chromium, fluorides, iron, manganese, nickel, nitrogen, and vanadium may form, as well as pyrolysis byproducts from fluxes and coatings. Welding on painted surfaces (e.g., lead-based paint) may produce a lead vapor hazard
Wet grinding	Wet grinding of any material may produce hazards of lubricating fluid mist, dust, and noise
Wet mixing	Solvent vapors, mist, and possibly, dust may occur. The noise levels produced by the equipment may be excessive

and may pose the most significant threat to human health. The profiles identify and review the key literature on each substance's toxicologic properties. Each profile includes a public health statement that summarizes the compound's toxicologic properties, a review of the information on human exposure, and known information on human health effects. The reviews are intended primarily for the use of health professionals, as well as private organizations and members of the public.

The National Institute of Environmental Health Sciences (NIEHS) of the United States Department of Health and Human Services prepares an Annual Report on Carcinogens, which reviews and evaluates information on evidence of carcinogenicity. The report provides a listing of chemicals classified on the basis of the strength of the evidence of carcinogenic risk. Chemicals may be classified as known carcinogens based on sufficient evidence of a causal association between the chemical and cancer in humans. Chemicals for which less convincing evidence exists may be classified as compounds reasonably anticipated to be carcinogens.

The American Conference of Governmental Industrial Hygienists (ACGIH) prepares a listing of TLVs and Biological Exposure Indices (BEIs), which is updated annually. The TLVs are recommendations intended to be used as guidelines for limiting occupational exposures to more than 500 chemical and physical agents. They are prepared by technical committees of the ACGIH, which is an association of occupational and environmental professionals from academia and governmental agencies. In addition to the annual TLV listing, the ACGIH publishes a companion volume of documentation for the TLVs, which summarizes the pertinent scientific information and data that were used as bases for the recommended exposure limits or indices.

Several international organizations review scientific information for purposes of evaluating risks resulting from human exposure to chemicals. The International Agency for Research on Cancer (IARC) prepares critical reviews of information on evidence of carcinogenicity for chemicals. The result of these reviews is a set of monographs that provide information on several hundred chemicals, mixtures, processes, and occupations. The IARC classification of the evidence on carcinogenicity ranges from category 1 (carcinogenic to humans; sufficient evidence of carcinogenicity) to category 4 (probably not carcinogenic to humans).

The International Programme on Chemical Safety (IPCS) is a joint venture of the United Nations Environment Program, the International Labor Organization, and the World Health Organization. This program develops Environmental Health Criteria Documents, which are summaries and evaluations of the information on toxic effects of specific chemicals and groups of chemicals. Over 200 chemicals have been reviewed and are published in the criteria documents, which summarize available information and include recommendations for further research.

Computerized Databases

NIOSH has developed a bibliographic database containing references of the occupational safety and health literature. The information sources for this database (known as NIOSHTIC) include approximately 160 English language scientific journals, NIOSH publications and reports, and references from the Chemical Information System (CIS) of the International Labour Office Occupational Safety and Health database. NIOSHTIC covers the following subject areas: toxicology, occupational medicine, epidemiology, pathology, physiology, engineering, industrial hygiene, health physics, behavioral sciences, ergonomics, hazardous waste, chemistry, and control technology. Each NIOSHTIC record contains bibliographic information, accession numbers to other systems such as NTIS and CIS, key words, and an abstract of 150 to 300 words. The database is updated quarterly and is available on-line or in CD-ROM form from several database vendors.

A comprehensive source of toxicity data is the Registry of Toxic Effects of Chemical Substances (RTECS) compiled by NIOSH. The original list was prepared in the early 1970s, and it is now available in printed form, in microfiche, on magnetic tape, in on-line databases, and on CD-ROM. It is updated quarterly in all versions except the print edition. The RTECS database currently includes approximately 250,000 substances. It is intended to be a comprehensive source of basic toxicity information for the assessment of hazards posed by exposure to chemical substances.

The National Library of Medicine has a computerized literature retrieval service known as the Medical Literature Analysis and Retrieval System (MEDLARS). Within this system are several specialized subfiles. MEDLINE is the largest database in the system, containing citations to the medical, toxicologic, and life sciences literature. There are several other specialized data files in the system, including TOXLINE (information on toxicity, biologic and chemical abstracts, drug and chemical metabolism, and pharmacokinetics), CHEMLINE (a dictionary listing chemical synonyms and Chemical Abstracts Service numbers), and TOXNET. A subfile of particular interest in TOXNET is the Hazardous Substances Data Base (HSDB). This file contains information about the toxic properties of approximately 4200 chemicals. In addition to data on toxicity, the system contains information on emergency handling procedures, environmental fate, human exposure, detection and measurement methods, and regulatory requirements. It contains information on molecular formulas, synonyms, methods of manufacturing, major uses, chemical and physical properties, protective equipment recommended for safe handling, summaries of toxicity determinations, exposure regulations and guidelines, methods for biologic monitoring for the chemical, and information on medical tests and procedures to be used for medical monitoring or in follow-up care for poisonings.

Resource Hotlines

A number of emergency response services are in operation, some of which are primarily intended to provide information on environmental aspects of chemical hazards. These services are good sources of information on the toxicity and risk of exposure to a wide range of chemicals, regardless of whether exposure takes place in an environmental or an occupational setting. NIOSH operates a toll-free technical service to provide information on workplace hazards. The service is staffed by technical information specialists who can provide information on NIOSH activities, recommendations, and services or any aspect of occupational safety and health. The number is not a hotline for medical emergencies but is a source of information and referrals on occupational hazards.

The NIOSH toll-free number is 800-35-NIOSH (800-356-4674).

CHEMTREC is a 24-hour hotline to the Chemical Transportation Emergency Center operated by the Chemical Manufacturers Association (800-424-9300). CHEMTREC assists in the identification of unknown chemicals, and provides advice on proper emergency response methods and procedures. It does not provide emergency treatment information other than basic first aid, however. CHEMTREC also facilitates contact with chemical manufacturers when further information is required.

The National Pesticides Telecommunications Network Hotline is operated through Texas Tech University (800-858-7378). The hotline provides information on pesticide-related health effects, toxicity, and minor clean up procedures to physicians, veterinarians, fire departments, first responders, and the general public. It also is a source of information on pesticide product formulations, basic safety practices, health and environmental effects, and clean up and disposal procedures.

Several hotline and information lines are available for response to information requests on toxic materials and environmental issues. The Center for Environmental Research Information is a central point for distribution of United States Environmental Protection Agency (USEPA) research results and reports (513-569-7562). The Toxic Substances Control Act (TSCA) Assistance Information Service provides information and publications about toxic substances, including asbestos (202-554-1404). In addition, each of the ten USEPA Regional Offices has a hotline telephone number.

EVALUATION OF HAZARDS

Industrial hygiene includes assessment of the nature and extent of human contact with biologic, chemical, and physical hazards in the work environment. In the study of occupational disease, industrial hygiene techniques are applied to identify, evaluate, and control the factors that cause disease. Although the techniques are tailored for the evaluation of each type of hazard, the principles of evaluation can be generalized.

Over the range of types of exposures (gases and vapors, aerosols, biologic or physical agents), there are two general classes of measurement techniques. One class may be termed the extractive methods, in which the contaminants of interest are removed from the environment for laboratory analysis. With these methods, a sampling device is used to collect the contaminants, usually from air in the vicinity of the worker's breathing zone. This sort of measurement attempts to characterize the composition of the environment at the point the worker contacts it. Most measurement methods assess airborne contaminants because of the importance of inhalation exposures; however, methods to measure contamination of surfaces, as well as the exposure of the skin, are available.

The second general class of measurement techniques determines the analyte directly in the atmosphere. These techniques are described as monitoring methods, and they are usually derived from instrumental methods first used in the laboratory. Devices that perform automated chemical analysis or make measurements based on chromatographic or spectrophotometric methods are common. These monitoring methods can measure continuously and report results immediately, which allows the examination of the pattern of exposure as it changes over time. This can be a substantial improvement over the information provided by extractive sampling methods, which accumulate material over the time of sampling, and give a result that is time integrated over that period.

Evaluating Current Hazards

Gases and Vapors

Over the range of exposures that are found in the work environment, the greatest number are typically present in the form of a gas or vapor. Of the 567 chemicals and materials for which there are OSHA PELs, approximately 300 are usually found as gases or vapors in the workplace. Because these materials pose a hazard primarily due to inhalation (although skin contact also may be a significant route of exposure), exposure measurement methods typically involve the collection of air near the point of inhalation. These measurements are called personal, breathing zone samples. Most gas and vapor sampling is performed by using a sampling medium that removes the contaminants from air and concentrates them for laboratory analysis. These sampling devices are small enough to be placed in the breathing zone of the person being sampled, and they usually contain solid materials that absorb the contaminants from air and retain them for analysis (materials such as activated charcoal, silica gel, and porous polymers are used). Other sampling devices contain liquids, which absorb contaminants based on their solubility or a reaction of the contaminant with the sampling solution. Air comes into contact with the collection media in these samplers either by active movement of air through the medium by a small portable pump, or by natural diffusion of the contaminants into the sampler to the collection medium. In both types of sampling devices, the total amount of contaminant collected during the sampling period is determined by removing the contaminant from the media (usually by chemical or thermal desorption), with analysis in a laboratory instrument such as a gas chromatograph or a high-performance liquid chromatograph. These devices may be coupled with a mass spectrometer to provide positive identification of contaminants.

An alternative method for air sampling is to collect a sample of air directly from the atmosphere using an evacuated container or a flexible bag. The composition of the air collected in this sample may be analyzed directly. Measurements made by these methods are described as grab samples. Because the absolute quantity of material collected by grab sampling techniques is small, these methods are generally limited to cases in which very small amounts of contaminant can be accurately measured. Materials for which other methods are not applicable, such as highly reactive or unstable contaminants that cannot be preserved for later analysis, also may be best measured by grab sampling.

Monitoring devices that can measure contaminants directly in the atmosphere are available for many gases and vapors. The simplest type of these devices are indicator or detector tubes containing a chemically treated material that changes color in response to exposure to a contaminant. These devices are small and extremely simple to use, and can provide semiquantitative determination of a range of airborne con-

taminants, such as carbon monoxide (CO), mercury, and many organic solvents. At the next level of complexity are portable instruments that directly measure a single contaminant, such as oxygen, or provide a composite measurement of all combustible gases in an atmosphere. These latter two measurements are commonly made in the workplace to determine the safety of entering a confined space, such as a manhole or a storage tank. The most sophisticated monitoring equipment is a set of instruments that are derived from devices previously used only in the laboratory. Instruments such as gas chromatographs with a range of detection systems, spectrophotometers, electrochemical monitors, and mass spectrometers have been miniaturized and made transportable for field use. These devices provide the sort of detailed identification and analysis of airborne contaminants that, until recently, has been only available by using extractive methods of sampling and analysis. Many of these devices are capable of providing continuous measurement of the concentration of airborne contaminants and displaying and recording the results in real time. This capability allows observation of the change in level and composition of exposure through time, which is a powerful tool in the analysis of sources of exposures. This detailed information about the characteristics of exposure also is useful in the development of methods to control these exposures.

Particulate Material

A wide variety of solid and liquid materials suspended in air may be important as causes of occupational disease. These suspensions of particles in air can be collectively described as aerosols, a term that includes air-containing solid particles (dusts), fine particles formed by condensation (fumes), and liquid particles (mists). The evaluation of exposure to these aerosols must consider the mass, quantity, and number of particles present in air (the concentration), as well as the size distribution, and chemical composition of the particles. As in the case of gases and vapors, exposure measures can be made by methods that remove the particulate materials from air for subsequent analysis, and by devices that measure the particulate content directly in air. Measurement methods that remove particulate material from air usually operate on the basis of the physical properties of the material, such as the particle size, mass, or electrostatic charge. Once the particles are removed from air, they can be subjected to a variety of chemical analyses to determine their composition, and they can be examined microscopically to evaluate their shape and size. These methods for collecting particles for analysis operate in a fundamentally different manner from the techniques used to extract gases and vapors from air. Even the smallest particles in an aerosol are many times larger and more massive than the molecules in the mixture of gases that comprise air. Particles that can be seen with an unaided eye are approximately 200 μm in diameter. (For comparison, a red blood cell is about 7.5 μm in diameter). Particles large enough to be seen are generally too large to penetrate beyond the extreme upper oral and nasal passages, whereas most of the particles, which are 100 times smaller (2-μm diameter), will enter and be deposited in the respiratory tract. Even these 2-μm diameter particles, although far too small to be seen, are vastly larger and heavier than the gas molecules in air, which have an average diameter of 0.0004 μm. Most particulate sampling methods, therefore, use this difference in size and mass between aerosol particles and molecules in air to remove aerosol particles for analysis.

The method most commonly used for personal measurement of aerosol exposures is filtration. As is the case for gas and vapor sampling, small filters can be placed in the breathing zone, and the aerosol particles are collected from air approximately at the point of inhalation. Several types of filtering media are used depending on the type of analysis that will be performed and the properties of the contaminant being measured. For example, the particulate material collected from air can be measured by chemical analysis for metals using a method such as atomic absorption spectrophotometry, or the organic fraction may be extracted from the filter and analyzed by a chromatographic method. Dusts such as those found in mining atmospheres may be analyzed for their mineralogic composition. In cases in which the shape and size of the particle are important factors in evaluating the hazard, such as is the case for asbestos and other mineral fibers, the collected particulate material is analyzed by counting and sizing the individual particles using optical or electron microscopy.

The hazard from airborne particulate material varies greatly, depending in large part on the site of deposition within the respiratory tract (see Figs. 1 and 4). The size of the particles, expressed as the aerodynamic diameter, is the major factor that determines the region of the respiratory tract where a particle may be deposited. Most aerosols found in the workplace contain mixtures of particles of widely varying sizes. It is not unusual, for example, to find particles ranging in size by a factor of 100 (i.e., an average diameter of 2 μm, but individual particles ranging from 1.0 to 100 μm) within an aerosol in a workplace such as a coal mine or a flour mill. When a worker is exposed to a mixture such as this, the inhaled particles are distributed throughout the respiratory tract on the basis of the particle aerodynamic diameter.

Because the toxic effect of a particle may depend on the region of the respiratory tract in which it is deposited, exposure measurements are made using methods that classify aerosol particles on the basis of their size. There are many types of air sampling devices that are designed to separate particles into fractions that correspond to the region of the respiratory tract in which they are likely to be deposited. This information about the size of the particles, along with the chemical analysis, provides the data needed to fully evaluate the hazard that an aerosol exposure may present. For example, it has been shown that humans absorb lead differently depending on whether uptake is from inhalation or ingestion. Depending on the size of an inhaled aerosol particle, it may be deposited in the deep alveolar region of the lung or it may be retained in the upper airways. The location of deposition is critical for a material such as lead, because virtually all the lead retained in the alveolar region is absorbed, whereas lead in the upper airways is cleared to the gastrointestinal tract, where it is absorbed with an efficiency of about 8%. The amount of lead contained in these small (less than 1 μm in aerodynamic diameter) aerosols may make a much greater relative contribution to the blood lead level than larger particles, which are deposited in the upper airways. Air sampling to assess a hazard such as this would be conducted using a device that separates the particles into two

or more fractions based on their aerodynamic diameter. Air samplers such as miniature cyclones or impactors are used to separate aerosols in this way so the size fractions can be analyzed separately.

There are a variety of more sophisticated instruments that directly measure the atmospheric concentration of aerosols. These instruments depend on the physical properties of the particles in air to provide the means of detecting and measuring aerosol concentration. For example, the tendency of particles to scatter light provides the basis for a family of instruments known as optical particle counters. In these devices, air is drawn into a chamber and a light source is focused on the air sample. Particles suspended in the air scatter a portion of the light, and this amount of light is proportional to the quantity of airborne material in the sample. Instruments incorporating lasers as the light source are capable of directly measuring the size as well as the concentration of the particles in an air sample. Another type of direct-reading instrument operates by subjecting the aerosol particles to electrical charges and measuring their movement in a charged field. These instruments also are capable of directly measuring the mass of material present in air and providing information about the size characteristics of the particles. A third type of instrument measures the mass of aerosol in a sample by collecting the particulate material on a surface, which is placed between a source of beta radiation and a beta radiation counter. The attenuation of radiation is proportional to the mass of particulate material from the sample, allowing the direct measurement of aerosol mass concentration in air.

Biologic Hazards in Air

Methods for evaluating biologic materials in air are a specialized set of techniques derived from the methods for measuring airborne particulate material. In terms of methods for air sampling, there are two general classes of biologic hazards: those considered viable, which pose a risk through their capacity to grow and multiply in an exposed host, and nonviable particles, which are hazardous owing to their ability to produce an allergic response, regardless of whether the exposure agent is viable. The methods for measuring exposure to these hazards tend to be specific to the agent being evaluated, and they are not standardized to the degree of general methods for measuring other aerosols. The importance of methods used to measure biologic hazards is apparent in studies of indoor environments, particularly in buildings with outbreaks of respiratory complaints and in health care facilities.

Measurement of viable materials in air requires the use of equipment that is similar to that used to measure other airborne particles, including filters, impactors, impingers, and open settling surfaces. These methods differ from those used for aerosol sampling because the viability of the collected material must be preserved. The techniques for detecting and enumerating viable organisms require that conditions be suitable for the collected material to grow into observable colonies or plaques. The sampling devices, therefore, include a growth medium, in which the collected microorganisms are retained or can be preserved in a viable state so they can be transferred to a growth medium after sampling. Depending on the purpose of the sampling, the growth medium can be tailored to support general growth, or it may be selective to favor the organisms of interest. In some investigations, the overall level of biologic contamination, measured in terms of total colony-forming units, may be important. Other investigations seek to address more specific concerns, such as the contamination originating from an air conditioning system in an office building. A study of this sort of problem would use selective media to evaluate particular types of microorganisms. The range of collection and culturing techniques for airborne microorganisms, as well as the specialized nature of investigations of biologic hazards, usually dictate that expertise in microbiology is needed to make measurements such as these and to interpret the results. Unlike other chemical and physical contaminants, there are no generally accepted standards for viable microorganisms in air.

The second type of biologic hazard is an airborne particle that produces an allergic response, regardless of whether or not the particle is viable. These particles are described as aeroallergens, and they include pollens, some bacteria, fungal spores, and insect body parts. These materials are collected from air using techniques including filtration, impaction, and gravitational settling. The properties of the collected material may be determined by microscopic examination, culturing for the viable fraction, and immunoassay for the antigenic component of the airborne material. These assay techniques are tailored to assess the property of interest, and investigations of airborne allergens usually are designed to address specific exposures.

Measurements of Hazards in Tissue or Body Fluids (Biologic Monitoring)

The use of exposure information in the investigation of occupational or environmental disease requires the assumption that exposure, as described and measured earlier, is a reasonable indicator or marker for the quantity of a toxic material that reaches a site in the body and elicits a response. Under some circumstances, this is a valid assumption and useful exposure response associations can be observed. There are, however, many factors that can compromise the value of exposure measures as predictors of health effects. Exposure is a measure of the concentration of a contaminant in the environment external to the body. As is mentioned in the discussion of air sampling procedures, measurements can be made as close to the actual point of inhalation as possible (the breathing zone sample), but the air collected at this point is not identical to that which is inhaled. Once the air enters the respiratory tract, the contaminants may be removed, distributed, and metabolized by many possible mechanisms. There can be a great deal of variability in these mechanisms between individuals, resulting in very different quantities of an active material at sites where toxic effects occur, even though the individuals may have had the same measured level of external exposure.

Another factor that complicates the assessment of exposure is the ability of many toxic materials to enter the body by several routes. In addition to pulmonary absorption, materials may be cleared from the respiratory tract and swallowed, resulting in uptake from the gastrointestinal tract. Many industrial materials also can be absorbed directly through the skin. Measurement of contaminants in body tissues or fluids reflects the contributions from these multiple

routes of exposure, as well as the variability in absorption, distribution, and metabolism between exposed individuals. Progress in biologic monitoring has been driven by the uncertainties about the relationship between measurement of contamination in the workplace environment, such as those made with conventional industrial hygiene air sampling methods, and the actual quantity of a toxic material that may be present in the body.

The measurement made in biologic media may be for a particular chemical itself or its metabolites. A reversible biologic change that is characteristically induced by exposure to a chemical is another type of measurement used to evaluate workplace exposure. These measurements can be made in blood, urine, exhaled breath, or other media. Biologic monitoring methods usually are used to complement measurements of inhalation exposures, because they provide information on the total exposure from all sources (nonoccupational and workplace), and by all routes (e.g., skin and gastrointestinal absorption). The medium that is selected for sampling can be chosen to suit a particular purpose, because materials such as organic solvents may be eliminated by several pathways. In workers exposed to *n*-hexane, for example, the solvent is rapidly cleared from the body in exhaled breath, with a biologic half-time of approximately 15 minutes. *n*-Hexane vapor may be measured in exhaled air during the period of exposure, providing information about the level of exposure in the short time before sample collection. An *n*-hexane metabolite also is excreted in the urine, so end-of-shift urine samples could be collected from the same workers and analyzed for 2,5 hexanedione, providing a time-integrated measure of daily exposure. There are reference values for measurements made in biologic media. ACGIH has prepared these values, known as Biologic Exposure Indices (BEIs), with documentation for their measurement and interpretation of results, for approximately 20 chemicals.

Interpreting Exposure Measurement Information

Information on exposure in the work environment may be collected for a number of purposes. Most frequently, exposure measurements are compliance driven, that is, the measurements are made to determine the levels of workplace contaminants with reference to an exposure limit or guideline. There are several sources of exposure limits, as discussed earlier. Although the exposure limit values vary between sources, virtually all these limits are specific to the airborne concentration of a single chemical, and the vast majority set a level that is not to be exceeded as a time-integrated TWA over an 8- to 10-hour work shift. Exposure measurements made to determine compliance with these exposure limits, therefore, usually are made in a manner that allows direct comparison between a worker's exposure level and the limit—as measures of a single contaminant, averaged over the full workshift. Although these data help determine compliance with a limit, they may not be useful as a predictor of health risk or the relationship between exposure and health effects. Several factors must be considered in interpreting exposure information, including simultaneous exposure to mixtures of toxic agents, variability in the composition and levels of exposure over time, exposure by multiple routes, and unusual working conditions. In addition, it must always be remembered that a given standard or limit may not be protective against a risk or health effect of interest.

Evaluating Mixed Exposures

Although most exposure limits are specific to a single agent, the working environment is likely to be composed of mixtures of potentially hazardous materials. In general, very little is known about the combined effects of exposure to multiple agents. The combined effects of some materials that act on the same organ system are recognized in the ACGIH TLVs for Mixtures. For example, an atmosphere containing a mixture of solvents, each of which may have neurotoxic effects, should be evaluated with consideration of the additive effect of the exposure. The TLVs provide guidelines for assessing the effect of exposure when the components of a mixture have similar toxicologic properties. Investigations of exposure-effect relationships provide some examples that illustrate the importance of multiple exposures. Studies of the respiratory effects of sulfur dioxide (SO_2), for example, demonstrate the potentiating effect of inert aerosols such as sodium chloride when the two materials are present as combined inhalation exposures. Exposure to atmospheres containing both SO_2 and an aerosol results in a much greater reduction in pulmonary flow than is observed for SO_2 exposure alone, whereas inhalation of sodium chloride aerosol alone has no effect on flow rates.

In epidemiologic investigations of exposure-response associations, the comprehensive assessment of exposure enhances the likelihood that a study will correctly identify and evaluate these relationships. Although these studies usually are conducted with some prior specification of the exposure(s) of interest, comprehensive exposure assessment is necessary to deal with confounding or effect modification by exposures that may not have been anticipated. One common pitfall of exposure assessment in these studies is discounting the possible role of an exposure as a causal agent because the association is not thought to biologically plausible. For example, the unexpected finding that CO exposure potentiates noise-induced, high-frequency threshold shifts illustrates the importance of conducting comprehensive assessments of exposure, even in cases in which a particular exposure is of primary interest.

Evaluating Exposure Variability

Exposure results from human contact with a contaminant in the environment. Regardless of the route (inhalation, dermal contact, or ingestion), exposure can be considered to be part of a pathway between the source of a contaminant in the environment to a site in the body where it can cause molecular or cellular damage. Exposure is measured as a marker of human interaction with a contaminated environment. Because the nature of this interaction can vary, the characterization of exposure should consider it as part of a dynamic process that changes through time, not as a fixed quantity.

The variability in exposure can be broken down into three major components. The *characteristics of the contamination*, i.e., the chemical make-up, or the distribution of particle sizes changes periodically over time. The second component is the *intensity of exposure*, expressed as its concentration, such as parts of benzene vapor per million parts of air, or

number of asbestos fibers per cubic centimeter of air. In many industrial environments, these characteristics of exposure are highly variable over a workday, resulting in a constantly changing exposure dose. The third major component of exposure variability is the *characteristics of the individuals* in the exposure environment. Even in jobs located at fixed work stations, where workers perform similar tasks, there can be substantial exposure differences between individuals because of personal work practices.

These sources of exposure variability must be considered in designing an exposure assessment strategy and in the interpretation of exposure information. When exposure varies widely over time, the time course of exposure must be considered. Industrial hygiene sampling methods that collect airborne contaminants for laboratory analysis provide a measurement that is integrated over the time of sampling. The temporal component of exposure variability is lost in such a measurement. For example, the atmosphere in a work environment could contain a steady state concentration of 1 ppm of a solvent, so the exposure of a worker spending a full shift in this area would be measured as 1 ppm as an 8-hour TWA exposure. Another worker could spend a full shift in an environment in which the level of exposure to the same solvent varied widely, from periods of no detectable exposure to very high but short-term peaks of exposure. If this second worker experienced a single, high-peak exposure level of 48 ppm of the solvent, for only 10 minutes a day, then spent the remainder of the shift in an unexposed area, this worker's 8-hour TWA exposure also would be 1 ppm. Interpreting these two exposures as equivalent, in terms of their likelihood of causing a toxic effect, could result in an erroneous conclusion if toxicity were based on the peak rather than cumulative dose at the target organ. Without any further information about the actual time course of the exposure, however, these two workers could be classified as equally exposed.

Exposure limits and guidelines are set in a manner that attempts to recognize that the risk of health effects resulting from extremes of exposure over time such as those just described may not be equivalent. For rapid-acting chemicals that are known to cause toxic effects from brief exposures, exposure limits can be designated as STELs. These values are intended to be levels measured over a short averaging period (usually 15 minutes), which should not be exceeded during any period, even if the 8-hour TWA does not exceed the exposure limit. These STELs are set to prevent irritation, chronic or irreversible tissue damage, narcosis, or other impairment that would result in material risk. For some acutely toxic chemicals, the exposure limit is designated as a ceiling limit, which is a level not to be exceeded at any time, even briefly. In practical terms, the duration of a ceiling exposure limit is defined by the shortest time period over which an exposure measurement can be made. Depending on the chemical of interest and the availability of methods for measuring its concentration in air, this limit may be a virtually instantaneous measurement, or the limitations of the measurement method may extend it to a period of approximately 15 minutes.

When exposure is used as a risk factor in studies of exposure response associations, unrecognized variability introduced by factors such as those just discussed can result in the incorrect assignment of exposure values to individuals or groups of workers. The result is misclassification of exposure among the members of the study population, which tends to obscure actual exposure-response relationships. In most studies, exposure is actually measured for a small portion of the population and only for part of the time period of interest. Based on these measurements and other information that may influence exposure, such as production conditions, presence of ventilation, or use of protective devices, exposure values may be estimated and applied to entire groups of workers. The assumption underlying this approach is that it is possible to identify groups of homogeneously exposed workers to which a single exposure value may be correctly assigned. The extent to which this assumption can be validated should be considered in the interpretation of study results, particularly in cases of studies that show no apparent association between exposure and response. This problem is especially serious in retrospective studies of diseases with long latency, because there is usually very limited historical information available on actual exposures. The likelihood of exposure misclassification is an important source of bias in epidemiologic studies.

Evaluating Exposure by Multiple Routes

Exposure assessment usually concentrates on the identification and measurement of airborne contaminants. The emphasis on air sampling derives from the importance of inhalation as a route of exposure for many occupational hazards. The skin also may be a significant route of entry for industrial chemicals. The OSHA permissible exposure limits, the ACGIH-TLVs, and most other exposure guidelines include notations indicating cases in which skin contact may be a significant route of exposure. In the case of the TLVs, this notation appears for approximately 10% of the chemicals listed. Unlike the methods used for measuring airborne contaminants, there are no well-established protocols for measuring skin contact with workplace chemicals. In addition, the interpretation of information obtained by measuring dermal contact is complicated by the absence of guidelines or reference values. Measurement of skin contact does not necessarily provide a direct indication of the quantity of a chemical that may be absorbed, because the relationship between the material found on the skin and the absorbed amount depends on several factors. The physical and chemical properties of the material, the anatomic area of contact, the duration of contact, and the individual characteristics of the exposed individual can all influence the relationship between the amount of material on the skin and the amount that may be dermally absorbed. The importance of dermal exposure should not be underestimated, however, because in some occupational settings, materials such as pesticides have been shown to enter the body primarily by this route.

Several techniques have been developed to measure contaminants on the skin, as well as on surfaces that may be sources of dermal exposure in the workplace. Cloth patches have been placed on the outside of workers' clothing and removed for analysis of chemical contamination as an estimate of the exposure of unprotected skin. A similar method has been used but with the patches placed under the workers' clothing to measure the quantity of a contaminant that penetrates the protective clothing. Exposure to the surface of the hands has been estimated by providing workers with thin

cotton inspector's gloves that are worn while they perform tasks in which dermal exposure is of interest. Analysis of the material on the glove then provides an estimate of the exposure of unprotected skin of the hands. This approach also has been used to evaluate the performance of protective gloves by wearing the cotton glove under the protective glove. Another technique used to estimate dermal exposure of the hands is to rinse the hands, or both the inside surface of the protective gloves and the hands after a worker has performed the task of interest. The volume of rinse solution is collected and analyzed for the contaminant. The measurement of surface contamination in a working environment can provide another, less direct indication of dermal exposure. Techniques for wipe sampling have been developed to measure surface contamination. These methods have been widely used in industries where exposure may result from resuspension of settled aerosols. For example, surface sampling for lead in industries such as foundries and lead smelters has been performed extensively. In cases in which the exposure of interest is nonvolatile, such as most metals and organic chemicals such as polychlorinated biphenyls (PCBs), surface contamination is a useful measure of the likelihood of exposure from skin absorption or ingestion resulting from eating or smoking with contaminated hands. There is a standardized surface wiping method specified by OSHA that describes techniques for collecting samples from contaminated surfaces.

Evaluating Unusual Working Conditions

Information on exposure should be interpreted in view of the overall conditions in the working environment. Even the OSHA PELs, which are legally enforceable, are not intended to be used as fine lines to distinguish between safe and dangerous working conditions. When interpreting the results of exposure measurements, an environment should not be considered to be free from risk when exposure levels do not exceed the limit value. In the case of individual workers in the environment, reported symptoms should not be considered nonwork related solely because measured exposure levels are below a limit. Any interpretation of exposure information should recognize that there is uncertainty associated with both the measurement of exposure and the limit value to which it is compared. The extent of individual variability in response to workplace exposure is not well known, and a conservative approach to the interpretation of exposure is always appropriate.

Among a number of factors that may influence the response to workplace exposures, the duration of the exposure period is one that has been recognized in the OSHA PELs. Exposure measurements are generally made with the expectation that the individuals are in the working environment for the normal 8-hour day and 40-hour work week. Many jobs, including a substantial portion of those in manufacturing, operate on a schedule that varies from this normal schedule. The potential effect of extended duration on occupational exposure may be recognized, but it is rarely quantified. Of the over 600 chemicals for which there are OSHA PELs, only the lead standard specifies that the maximum daily allowable exposure level be adjusted down in proportion to the time by which the length of the daily exposure exceeds 8 hours.

Another factor that should be considered in the interpretation of exposure information is the time of day during which the exposure occurred. At least 20% of the workforce in manufacturing jobs works other than daytime schedules. Although limited information is currently available on the physical and psychologic effects of shift work, overall job performance, as well as behavioral and psychologic function, is diminished in night workers compared with day workers (see Chapter 29). The possibility of combined effects of exposure and the time of day during which it occurs should be considered in investigations in which both factors could affect the outcome of interest.

ASSESSING PREVIOUS WORKER EXPOSURES

Many occupational and environmental exposures produce clinical disease many years after the initial exposure. Knowledge of past exposures, therefore, is important for establishing a causal association. Estimating past exposures requires a systematic approach to information gathering. First, an inventory of potentially toxic substances and exposures for different jobs must be developed. This effort requires knowledge of industrial processes and materials, and familiarity with the toxic substances present in the historic environments.

Use of Past Exposure Measurement Data

In ideal circumstances, quantified personal monitoring data, obtained from air sampling or other dosimetric methods (e.g., radiation film badges), may be available. However, in the more typical situation, quantified exposure data are sparse or nonexistent. Even when data are available, they often represent special exposure situations that were measured in response to particular concerns about workers' health or because of compliance enforcement requirements. Evaluations of sampling data are best determined when there is documentation of the circumstances under which exposure measurements were taken. Furthermore, industrial hygiene data tend to be most complete for recent years in which promulgated exposure guidelines and standards have required initial and periodic exposure monitoring.

For epidemiologic investigation, rather than for clinical evaluation, these limitations may be more serious, even rate limiting. Industrial hygiene sampling data measuring individual exposures are by far the most useful for classification. It is usually not feasible to measure all exposures for all individuals; therefore, samples are collected that are thought to represent adequately exposures of employees doing the same or similar tasks. Typically in epidemiologic studies, attempts are made to assign workers to various exposure classifications, based on the type of exposures and exposure levels. Industrial hygiene sampling data are useful for this purpose when sufficient descriptive data are recorded to allow identification of individual workers or specific jobs for which the exposure data pertain.

Because exposures can change qualitatively and quantitatively over time, it is important that these changes be taken into consideration. Changes in industrial hygiene and analytic laboratory techniques may diminish the validity of some past exposure monitoring data.

Special sampling studies may be needed for correlating

results from different measurement methods and for assessing the validity of the exposure rating scheme—at least in reference to current exposure levels. For example, asbestos exposure was formerly measured in units of particles per cubic foot rather than fibers per cubic centimeter. Use of old data in that form may require simultaneous use of old and new measures to allow valid conversion of the old data to the new.

Estimates of Exposure Potential Using Surrogate Data

In the absence of complete quantified exposure data, potential occupational exposures can be identified using plant raw material, process, and control information. Jobs and work areas can sometimes be classified with respect to exposure levels and potential exposures. A job-exposure matrix, which links work histories with exposure data for clinical and epidemiologic analysis, frequently is generated.

The types of information that the industrial hygienist incorporates into the exposure rating scheme include data from the following: air sampling, physical agent exposures (e.g., noise dosimetry), biologic monitoring, materials usage records and purchase orders, plant production records, job and task descriptions, and documentation of engineering controls and use of protective equipment. Table 2 provides a summary of data useful for estimating exposures. The following are potential uses and limitations of various data sources with respect to estimation of past exposures:

1. Process descriptions, flow charts, and plant layout: Changing plant process and raw materials may affect significantly actual or potential occupational exposures. Process changes often result in new raw materials or intermediates of potential health significance. Proximity of plant operations to each other also may be important. Ideally, plant records should be maintained in sufficient detail to permit identification of dates of process changes or major changes in plant layout or equipment.

TABLE 2 Sources and Types of Information Useful for Evaluating Past Exposures

Company records	
	Process, descriptions, flow charts, and plant layouts
	Job and task descriptions
	Raw materials and intermediates, by industrial process
	Plant production records
	Engineering control records
	Industrial hygiene sampling records
	Physical and biological agent measurements
	Personal protective equipment availability and use
	Inspection and accident reports
	Biologic monitoring results
	Environmental discharge and incident reports
Labor union records	
	Records of work locations
	Injury and illness records
Government records	
	OSHA or state program inspections
	NIOSH studies and Health Hazard Evaluation Reports
	State OSHA or consultation reports
	Workmen's Compensation Records
Insurance company records	
	Plant inspection/reports
	Industrial hygiene studies

2. Job and task descriptions: The most commonly used method for assigning employees to exposure categories in epidemiologic studies is the classification of job titles. In studies in which only a few significant exposures are present, job titles generally allow suitable stratification into exposed and nonexposed populations. Changes in job titles occur over time, and this factor should be recognized. Although job titles are useful for exposure classification, additional information—such as specific tasks performed and plant location—may be needed to appropriately classify exposures.

3. Raw materials and intermediates, by process: Raw materials and intermediates should be recorded in sufficient detail to allow identification of processes or plant areas where raw materials are used; changes in these factors also occur over time. Because it usually is not possible to measure all exposures in a given process or area, it is important that the materials list be as complete as possible so that multiple potentially hazardous exposures may be evaluated. Purchase records can be a valuable source of information on the type and quantities of materials used.

4. Plant production records: In addition to raw materials, plant production or output rates may affect exposures. In many instances, changes in measured exposures without other apparent plant changes can be attributed to increased or decreased processing of the materials in question. Annual production volume by product may be useful as a measure of change in potential exposures.

5. Engineering control records: Engineering controls are the preferred method for controlling occupational exposures and, typically, change significantly over time. Engineering records should be maintained in sufficient detail to identify controls by process or equipment over time. Both control system design and operational parameters are important. Special studies evaluating the effectiveness of engineering control measures are especially useful because these studies may suggest important changes in employee exposures. Photographs can be valuable supplements to such record systems.

6. Physical and biologic agents: Plant raw materials lists are usually helpful in identifying potential chemical exposures; however, additional records often are necessary to characterize exposures to physical and biologic agents. Physical agents include ionizing and nonionizing radiation, noise, and vibration; biologic agents include viruses, bacteria, fungi, and other microbial antigenic material. Exposures to physical and biologic agents often are generated within the workplace rather than resulting from the intended use of defined raw materials. The presence or absence of such exposures often must be inferred from information about equipment and processes.

7. Personal protective equipment: Personal protective equipment—such as respirators, gloves, protective clothing, and hearing protection—may significantly affect actual worker exposures. In addition to recording protective equipment in use during industrial monitoring studies, documents detailing protective equipment policies and procedures may be helpful.

8. Inspection and accident reports: Accidental spills or leaks may represent significant exposures that must be considered when drawing conclusions from epidemiologic studies. Spills or accidents can result in greater potential for atypical routes of exposure, such as clothing contamination and skin contact. Failure to account for such exposures can

lead to incorrect conclusions concerning health effects of usually low exposures. Incidents such as major spills or leaks may be documented in sufficient detail to allow for estimation of the potential severity of exposures as well as to identify workers potentially exposed.

9. Biologic monitoring results: Although results of blood, urine, breath, and other types of biologic monitoring usually are maintained in medical departments, they also are frequently used by industrial hygienists for exposure monitoring. These data are especially valuable when there are multiple routes of exposure, such as inhalation and dermal absorption.

10. Environmental discharge and incident reports: Health effects among residents of neighborhoods in close proximity to industrial plants may be of concern. Federal regulations require annual reports of environmental discharges for specified pollutants for certain manufacturing facilities.

11. Employee surveys and interviews: Surveys of long-term employees, in which workers are asked to rate jobs according to perceived relative exposure intensities, provide ancillary information. Questionnaire survey results are most reliable when the variations in exposure levels of the agent of concern are readily apparent (e.g., dust, malodorous fumes, irritating gases). Validation of judgment with objective information (e.g., some measurements) is desirable.

Historical reconstruction of workplace exposures is essential to the validity of occupational epidemiology and for establishing a causal relationship between exposure and a disease. When sufficient data exist that permit a quantitative exposure rating scale, it is possible to estimate, within reasonable limits, true exposure intensities. Estimates of potential exposures using production-related data also are useful for epidemiologic research and for relating workers' symptoms and disease with possible occupational exposures.

Linkage of Industrial Hygiene and Medical Data for Epidemiologic Study

The link between industrial hygiene data and health outcome data, available from medical surveys or death certificates, is ordinarily the file of employer personnel records for workers in the study population. From such records, work histories, indexed by time interval at various exposure levels or by exposure surrogates, can be constructed. Techniques for and difficulties associated with linking information on work conditions with industrial health data have been discussed by investigators active in this area (see Chapter 9, Epidemiology).

Direct exposure measurements from monitoring surveys that are specific for individual workers offer the best exposure data. More commonly, occupational epidemiology studies rely on exposure estimation when jobs and tasks within the industry are assigned exposure-intensity levels. Creation of an exposure matrix that is specific for jobs, tasks, and calendar years that can be linked with employee personnel records has become standard procedure in many epidemiologic studies. This approach allows for aggregation of jobs and tasks according to either exposure levels or similarity of tasks and materials handled, depending on the extent of available information.

The types of data that can be used in linking industrial hygiene and health data include the following: industrial hygiene survey data, job classifications and descriptions, personnel employment records of workers, information on work location within a plant for specific jobs, and when available, medical records. Medical records, although most valuable as a source for case finding for injuries, accidents, dermatitis, and other nondisabling conditions, sometimes contain results of biologic monitoring that can be an ancillary source of exposure classification.

Existing industrial hygiene or health physics sampling data, which are of obvious research value, may need to be augmented by currently obtained measurements in cases in which many jobs cannot be classified into exposure level categories. When major changes in sampling and quantification technology have occurred over time, it may be inappropriate to add the newly obtained data to the historical data. Instead, the new data can be incorporated to generate ordinal exposure scales for the various jobs in the plant or to confirm judgments that certain work locations and jobs probably entail minimal exposure to an agent of concern.

Resources seldom permit extensive industrial hygiene surveys; thus, a selective approach is recommended in which special groups of workers or job types are targeted for monitoring. These groups can be workers for whom data have never been collected or workers in jobs in which previous research has indicated important disease risks. Maintenance, crafts, quality control, and laboratory workers are groups that frequently are unmonitored. Periodic monitoring surveys of these workers, especially maintenance workers, who represent sizable proportions of the workforce in many industries, would serve to rectify the common problem of unknown exposure profiles. Almost invariably there are some jobs that cannot be classified according to exposure level, either because there is inadequate job description (e.g., the laborer designation) or because sampling cannot be performed. This circumstance necessitates the creation of an unknown exposure category for some workers. The health experience of such workers should be evaluated in a manner similar to that of workers with estimable exposure profiles, although the results for the unclassified group are less informative. Removal of workers with unknown exposures from the study would be wasteful of information and may introduce bias into the assessment.

The job and exposure matrix that is generated should be documented carefully so as to indicate the basis for assignment of exposure levels. Thus, the industrial hygienist should maintain a file that indicates each job or task included in the analysis—the exposure value or rankings—by time period and the data sources that were used to derive exposure estimates. The source information should indicate whether a given estimate was based on industrial hygiene sampling data, the nature of the sampling (e.g., area or personal, compliance, or routine monitoring), the number of samples and the range of values, and whether the estimate was based on judgment.

Ultimately, the epidemiologist is presented with a data file containing exposure information for the study subjects that summarizes data from all available sources. There are important benefits to maintaining such an exposure assessment inventory. First, documentation of the exposure estimation data sources and procedures facilitates future updates of the study and reanalyses of the data. Second, the exposure matrix

that can be applied to work history data for the entire study population generally represents the lowest common denominator of the precision of exposure data. For example, it may be possible to estimate quantitatively cumulative exposures for one half of the study population. Although they are only ordinal (high, moderate, and low), exposure classifications are available for all other workers. In this instance, an analysis of the entire population's disease risks in relation to exposure would be limited to an ordinal exposure classification of workers. The exposure assessment inventory, however, would permit secondary, more exacting analyses of exposure-effect relationships to be performed on the subset of workers with quantified exposure estimates. Finally, an inventory of this type protects the investigators when the study procedures and data are reviewed by other investigators, regulatory agencies, or legal representatives.

CONTROL OF HAZARDS

Principles and Limitations of Controls

Hazard control in the working environment is the goal of occupational hygiene. The elimination or reduction of hazards to the greatest extent feasible is the primary means of prevention for occupational disease and injury. The strategy for effective hazard control is an ordered hierarchy, which has been described as follows:

1. First, prevent or contain hazardous workplace emissions at their source;
2. Next, remove the emissions from the pathway between the source and the worker;
3. Last, control the exposure of the worker with barriers between the worker and the hazardous work environment.

This strategy mandates the use of engineering control methods in the environment as the primary means of exposure prevention. These controls may be implemented in several forms or in combinations as part of an overall prevention strategy. The methods include substitution of these harmful materials with less hazardous substances, modification of the working environment to contain the source of the hazard, isolation of the worker from the hazardous environment, removal of the hazardous substance by ventilation, modification of work practices to reduce exposure, and use of personal protective equipment to reduce exposure. The use of protective equipment, including respirators, is intentionally mentioned last. Respiratory protective equipment should be considered the least preferable means of hazard control, implemented only when other means of control are not feasible or effective.

Material Substitution

One method of direct intervention to reduce workplace hazards is the removal of a toxic material and its replacement with a less toxic substitute. This practice is well established as a means of reducing risk in the workplace as well as in the general environment. Elimination or reduction of extremely toxic materials, such as asbestos as an insulating material or benzene in solvents, adhesives, and gasoline, illustrates the principle of substitution. These examples also demonstrate another factor that must be considered in substitution: the risk of replacing one hazard with another. Some of the materials used to replace asbestos as an insulating material, such as human-made mineral fibers and fibrous glass, are suspected of having effects similar to asbestos as more information is discovered about their toxicity. The replacement of benzene with another chemical with similar solvent properties, such as hexane, may reduce the risk of exposure to a carcinogen but increase the hazard of exposure to a neurotoxin. Substitution is an important method of primary prevention of workplace exposures, but it should be practiced with a recognition of the effect the replacement material may have on the work environment. The result of substitution should not be the replacement of one hazard with another.

Process Modification

The introduction of contaminants into the work environment may be prevented by changing the characteristics of the source. The application of engineering control technology in the design of industrial processes is a very effective method of intervention to reduce exposures. For example, the technology of spray painting has changed, substantially reducing solvent exposures by using airless atomization systems instead of compressed air spray guns. Many common industrial processes, such as material-handling procedures can be redesigned to minimize the release of contaminants. At the design stage of a new industrial process or in the modification of existing operations, exposure control should be included as a central design element. The anticipation and control of potential hazards at the design stage is more efficient than remediation of existing conditions.

Isolation

Isolation is an effective method of intervention to interrupt the pathway between the source of a hazard and the worker. The general approach of isolation can be implemented in two ways: (1) by enclosure to isolate a source from the working environment or (2) by isolating the workers from a contaminated environment. Although a comprehensive exposure control strategy may include both approaches, containment of the source is generally preferable.

A common example of containment as a means of hazard control is the glove box used in handling infectious materials, extremely toxic chemicals, and radioactive materials. This approach is particularly well suited to control individual point sources of contaminants or physical hazards such as noise. By preventing the release of a hazardous agent into the work environment, exposure is controlled at the source.

In cases in which contaminants are released from multiple sources dispersed throughout the work environment, isolation of the workers from the contaminated environment may be preferable. Although this approach does not prevent the release of the hazard into the environment, it is possible to control exposure by protecting workers through isolation. The use of clean air–supplied control rooms in chemical production facilities is an example of isolation of workers from general environmental contamination.

Administrative and Work Practice Controls

Measures can be taken to limit or restrict the opportunity for exposure through changes in the manner in which work is

performed. These controls are a hybrid, incorporating some features of source control and some modifications of work practices. Administrative controls may be implemented to prevent release or contain hazardous emissions at their source. In the health care setting, for example, administrative controls such as rapid identification, early treatment, and isolation of potential tuberculosis transmitters; limiting worker access to acid-fast bacilli (AFB) isolation rooms; and other administrative procedures could be implemented to reduce risk of exposure. Modification of procedures such as using portable x-ray units in the room of a confirmed or potential tuberculosis transmitter rather than moving the infectious person to the central x-ray department is another example of the use of administrative control to reduce the chance of exposure.

Work practice modifications also can be implemented to reduce exposures. For example, methods used for clean up of lead-containing dust at weapon firing ranges makes a significant difference in the general level of contamination and personal exposure. Instead of using brooms to sweep up dry dust, which generates large amounts of lead-containing aerosols, vacuuming with equipment incorporating high-efficiency particulate (HEPA) filters keeps lead dust from being resuspended, significantly reducing exposures. Analysis of individual work tasks also can identify practices that contribute to exposure. Painters using spray guns in ventilated booths, for example, may unnecessarily increase their exposure to solvent vapors by moving into the booth when they paint the back side of a large part, rather than turning the part so they always can spray paint into the booth. Changes in work practices such as these can reduce exposure significantly, and they are most likely to be effective when they are developed through on-site evaluation, with full participation of the workers who are actually performing the job.

Ventilation

In the working environment, ventilation is a central component of hazard control. There are two general types of ventilation: (1) dilution ventilation (also known as general or comfort ventilation) and (2) local exhaust ventilation. Virtually any indoor space has some amount of dilution ventilation, even if it is only the natural infiltration of outside air. The control of contaminant sources in the workplace frequently requires additional ventilation in the form of local exhaust to capture contaminants at or near their source and remove them from the work environment. These two types of ventilation are very different in design and performance, and are discussed separately.

Dilution Ventilation

Dilution ventilation operates on the principle of replacement of contaminated air with fresh air. The simplest form is the natural entry of outdoor air through drafts around windows, doors, and other openings. Most buildings used as places of employment have at least some means of providing mechanical air movement to supplement the natural airflow. Mechanical roof ventilators or wall fans are common in buildings used as workplaces. In office buildings, where there are no industrial processes that release contaminants, the human occupants may be the primary source of indoor pollution. General building air provided by a heating, ventilation, and air conditioning (HVAC) system may be the only means of controlling the carbon dioxide, water vapor, particulate material, and biologic aerosols that are the result of human occupancy. Ventilation guidelines for general dilution are provided by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to specify minimum ventilation rates and indoor air quality that provide an acceptable work environment to building occupants, and the quantity of ventilation needed "... to minimize the potential for adverse health effects." (See also Chapter 39, Indoor Air.)

For workplaces where there are sources of contamination in addition to human occupancy, dilution ventilation is generally not an effective control method. It may be applicable in a limited number of situations only when several criteria are met. Typically, dilution ventilation may be adequate in workplaces where small amounts of contaminants are released at uniform rates. In these cases, a reasonable amount of air added to the work space may be sufficient to dilute the contaminants to a level at which they do not pose a hazard. This approach is limited, therefore, to contaminants with low toxicity and environments in which workers do not have contact with the contaminant until after it has been diluted. The volume of air that is needed to dilute contaminants to acceptable levels is usually large, requiring large and expensive air-handling systems to move the air, as well as to heat and cool it. The lack of positive control over the sources of contaminants, as well as the high airflow requirements and operating costs usually limit the usefulness of dilution ventilation systems as exposure control methods in the workplace. These systems may reduce the amount of contaminant present in the work environment, but they do not control its release.

Local Exhaust Ventilation

Local exhaust systems differ fundamentally from dilution systems. The operating principle of local exhaust ventilation is the capture of air contaminants at the source, preventing their dispersion in the environment. These local systems control emissions and prevent exposures, interrupting the pathway between the source of the contaminant and the worker.

Local exhaust systems are usually tailored to the source they control. The components of the systems include the hood, which is the device to capture the air and facilitate its entry into the exhaust system; the fan, which provides the force to move air into the system; and the duct work connecting the hood and the fan. Many systems also include an air-cleaning device, such as a filter, to remove contaminants before the air is released to the environment. The hood, which is the collection point of the contaminated air, is typically designed in a manner that encloses the source to the greatest extent possible. It may be designed to fit around the shape of existing machinery or to receive material that is released from the source, such as the metal particles thrown from a grinding wheel or the dust created by a circular saw. (Fig. 6)

The design and testing of local exhaust systems is a specialized aspect of ventilation engineering. There are several sources of guidance that are very useful in the construction of systems that are effective in controlling exposures by local

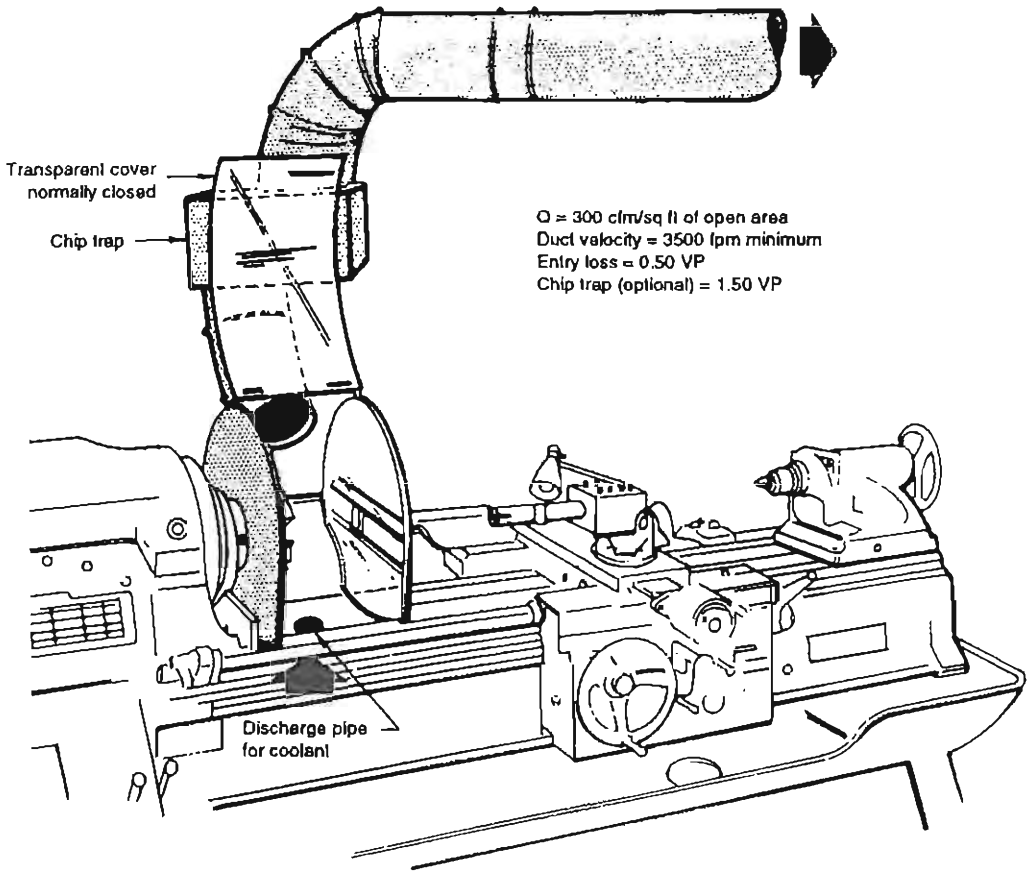

FIGURE 6 An example of local exhaust ventilation, in this case used over a lathe-generated coolant mist and possible metal dusts.

ventilation. These sources are included in the bibliography, and they should be consulted as sources of further information.

Personal Protective Equipment

A variety of devices are available to provide a barrier between a worker and a contaminated environment. These devices include equipment to protect the eyes, such as safety glasses, goggles, and face shields. There are many types of skin protection, including gloves, aprons, and full-body suits made of materials that are impervious to chemicals. The selection and use of these devices is largely driven by the particular application, and there is a large number of choices of protective equipment available.

The choice of chemical protective clothing for the skin usually centers on gloves, although the principles guiding the selection can apply to devices that protect part or all of the body. The selection of chemical-protective gloves should include an analysis of both the job task and the exposure against which protection is needed. The job task analysis should consider ergonomic factors, such as the manual dexterity, grip, and tactility required by the task. The duration and frequency of the task should be determined, as well as the physical properties that will be required of the gloves (resistance to tearing, cutting, and abrasion; flexibility; puncture resistance). The analysis of exposure should include identification of the chemicals involved, their physical state and properties, and the nature of the health hazards they present. The MSDS may be a good source of information to guide the selection, and specific recommendations for gloves are generally included on the MSDS. This guidance should not be used as a substitute for a thoughtful analysis of each job-task-exposure situation, however. The demands of each work environment and characteristics of the individual worker must be considered in the selection process.

Information on the properties and characteristics of gloves is available from a number of sources. The manufacturers of gloves and other chemical-protective clothing can provide data on their products. Publications that summarize the available data that can be used in the selection of gloves include "Guidelines for the Selection of Chemical Protective Clothing" (Schwope et al, 1987) and "A Guide for Evaluating the Performance of Chemical Protective Clothing" (NIOSH, 1990).

Respiratory Protective Devices

Respiratory protective devices are used to provide protection from exposure by inhalation. There are several factors that must be considered in the use of respiratory protection beyond the general considerations for other protective devices. OSHA has a specific regulation for respirator use (Code of Federal Regulations, 29 CFR 1910.134). In addition, some OSHA standards for air contaminants, such as asbestos and lead, include requirements for respiratory protection programs. These legal requirements, as well as the importance of matching the choice of respiratory protection with both the hazard and the individual respirator user make respirator selection and use more complex than is the case for other

protective equipment. The correct choice of a respirator depends on the identity of particular contaminants that may be present and on the concentrations at which they will be found in the working environment. The ability of an individual worker to wear the respirator in a manner that provides adequate protection also must be determined as part of a respirator selection and use program. The degree of protection that a respirator provides in actual use in the working environment varies widely among individual workers. Comprehensive respiratory protection programs must include respirator fit testing to ensure that each respirator performs effectively for the individual user.

There are two general types of respirators (Fig. 7). Some respirators remove contaminants from air by filtration, adsorption, or chemical reaction. Respirators that operate by the principle of removing contaminants are described as air-purifying respirators. Respirators that supply air from a source other than the surrounding environment (such as from a cylinder of compressed air) are known as atmosphere-supplying respirators. Both types of respirators are tested and certified for use by NIOSH and MSHA. As a guide to the selection and use of respiratory protection, NIOSH has developed a respirator decision logic, which is a recommended procedure for choosing respirators suitable for protection against contaminants.

The elements of the NIOSH respirator decision logic are summarized in the following section. The full text of the decision logic is available free of charge from NIOSH (call the NIOSH toll-free number, 1-800-35NIOSH, or the publications office at 513-533-8573). In order to select the correct respirator for any work situation, a substantial amount of background information is needed. This information includes the general conditions in which the respirator will be used; the identity and concentrations of the airborne contaminants that will be present; the physical, chemical and toxicologic properties of the contaminants; the odor thresholds of the contaminants; the NIOSH and OSHA recommended and PELs for the contaminants; the immediately dangerous to life and health (IDLH) concentrations; the potential for eye irritation posed by the contaminants; and any available information on the service life of the air-purifying cartridges used in the respirator. Using this information on the likely hazards and the nature of the work situation where respiratory protection may be used, the decision logic can guide the selection of the proper protective device.

In practice, the decision logic takes the form of a set of questions. The response to each question guides the user through a decision tree, with more detailed information elicited at each level, leading to the selection of the respirator that is recommended for each situation. For example, the first level of information requires concerns about the anticipated use of the respirator. If it is intended to be used in fire fighting, for protection from oxygen-deficient atmospheres, to be used in emergency situations, or for protection against human carcinogens, then an atmosphere-supplying respirator is recommended. If the contaminant is an eye irritant or can damage the eyes at the concentrations expected, then a respirator with a full facepiece is recommended.

The next level of questioning in the decision logic concerns the physical state of the contaminant. If the contaminant is a particle (a dust, mist, or fume), then the respirator is chosen from one of several types that contain a filter to remove particles during the inhalation cycle. These respirators range from simple, disposable masks that are intended for a single use to full facepiece respirators with HEPA filters, up to positive-pressure atmosphere-supplying or self-contained respirators. If the contaminant is a vapor or gas, there is a comparable set of choices, ranging from air-purifying half-mask respirators with chemical sorbent cartridges to positive-pressure atmosphere-supplying respirators with full facepieces.

The actual choice of the appropriate respirator is made

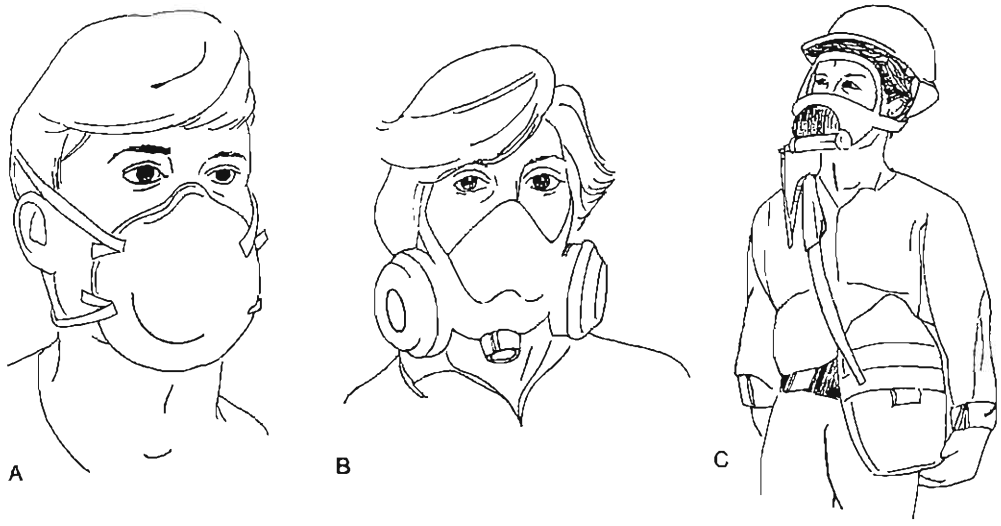

FIGURE 7 Examples of the most widely used types of respirators. *(A)* A disposable respirator and *(B)* an air-purifying (cartridge) device. Both of these respirators filter or purify air under the negative pressure of breathing. Air may also be filtered actively by a powered air-purifying respirator (PAPR), not shown. *(C)* A self-contained breathing apparatus (SCBA). This device provides clean air under positive pressure. Another type of positive pressure respirator, the air-line respirator (not shown), delivers fresh air from a stationary tank through a long tube.

with consideration of the assigned protection factor for the respirator and the expected concentration of the contaminant(s) that are present in the working environment. The assigned protection factor (APF), which is the ratio of the concentration of the contaminant outside the mask to the concentration inside the mask, is the key to evaluating the respirator's efficiency at removing airborne contaminants. For example, a single-use disposable dust mask may have an APF of 5, meaning there is a five to one ratio between the concentration of the contaminant in air outside the respirator to the concentration inside the respirator. Put another way, such a respirator would allow 20% penetration of the contaminant it is designed to protect against. A full facepiece respirator with an HEPA filter would have an APF of 50, allowing only 2% of the contaminant to penetrate. In practice, the APF guides the selection of the respirator to the one that provides sufficient protection. To choose a respirator for a particular exposure situation, the expected concentration of the contaminant (either an 8-hour TWA, or a short-term concentration) is divided by the exposure limit for the contaminant (the OSHA PEL, the NIOSH REL, or some other exposure limit). The result of this division is the minimum respirator protection factor required. For example, suppose respirators were being considered to protect workers in a factory where exposure control measures such as ventilation were either not feasible or were in the process of implementation to reduce exposure to Portland cement dust. The OSHA and NIOSH exposure limits for total Portland cement dust are 10 mg/m^3. If the expected dust concentration in the workplace were approximately 20 mg/m^3, then the minimum respirator protection factor required would be 20 divided by 10, or 2. Using the tables of APFs for the various types of particulate respirators, as described in the respirator decision logic, a properly fitted single-use respirator (which has an APF of 5) would be appropriate. If the exposure agent were a material of greater toxicity, such as the pesticide Endrin, which has an OSHA and NIOSH exposure limit of 0.1 mg/m^3, protection against an atmosphere containing 20 mg/m^3 of the contaminant would require a respirator with a minimum protection factor of 200, which would indicate that a positive-pressure supplied-air respirator is needed.

Respirators can provide effective personal protection only when they are properly selected and when they are used in the context of a comprehensive respiratory protection program. OSHA has specified the minimum requirements for an acceptable program (29 CFR 1910.134). In order for respirators to provide adequate worker protection, both the proper selection and the correct use of respirators are essential. Despite the apparent simplicity of respirator use, respirators can be unreliable if not selected and used in a comprehensive protection program. Respirators are the least preferred method of protection from respiratory hazards, and they should be used only when engineering controls are not technically feasible, while controls are being installed or repaired, or in emergency and other temporary situations.

EDUCATION AND TRAINING

Worker education and training are key components of effective primary prevention programs for workplace injuries and illnesses. Workers must understand the physical and chemical hazards associated with their work as well as methods for controlling these hazards. Worker *training* is defined as instruction in recognizing hazards and in using available methods of worker protection, whereas worker *education* is defined as instruction in analyzing and responding to new circumstances and conditions.

OSHA substance-specific regulations, such as those that apply to asbestos, lead, arsenic, and cotton dust, require worker education and training, although these regulations often lack detailed training specifications. Training requirements also are contained in several OSHA process-specific standards, such as the respiratory protection standard, the blood-borne pathogens standard, and the standard concerning process safety management for highly hazardous materials. In addition, the OSHA Hazard Communication Standard, which was promulgated in 1985, establishes generic training requirements for hazardous substances.

The OSHA Hazard Communication Standard requires chemical manufacturers and importers to provide hazard information to users of their products. Information must be provided in the form of MSDSs and product labels. The standard requires that employees be provided with information and training on hazardous chemicals in the workplace. Training must include

1. Information concerning requirements of the OSHA standard.
2. Identification of hazardous materials in the work area.
3. Information on the company's written hazard communication standard.
4. Methods for detecting the presence or release of hazardous chemicals in the work area.
5. Specific hazards of chemicals in the workplace.
6. Measures to protect workers from exposure to hazardous chemicals.
7. Details concerning the employers' hazard-labeling system for chemicals in the workplace.

Quality worker education and training must consider special needs of the worker and appropriate means of training delivery. Although OSHA standards require training, little specification is provided concerning training content, delivery, or quality assurance. NIEHS has recognized the need for greater attention to worker training quality issues in connection with training programs for workers involved in hazardous waste clean up and emergency responses to spills of hazardous materials. A consensus working group has developed minimum criteria recommendations for worker training quality assurance. The key components of these recommendations include (1) experienced training program staff; (2) a well-defined training plan with tested curricula and materials; (3) students with prerequisite job skills; (4) adequate training facilities, including provisions for hands-on training and demonstrations; and (5) quality control and evaluation plans, including adequate peer review of the training program.

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