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with 163 illustrations

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Chapter 4

PRINCIPLES OF EXPOSURE ASSESSMENT

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EXPOSURE ASSESSMENT

Exposure is an event or series of events in which a person (or population) comes in contact with a biologic, chemical, or physical agent. Assessment of this exposure is an important endeavor that is required as a first step in many applications, including compliance with legal standards, disease diagnosis and treatment, risk assessment and management, and occupational and environmental epidemiology. The underlying assumption is that there is a causal relationship between the amount of exposure to an agent and the extent of observed health effect. The concept of dose is used as a descriptor of the administered quantity of the agent. Thus the dose is the physiologically (and pathologically) significant characteristic of exposure. The National Research Council has defined the dose as the amount of the contaminant that is absorbed or deposited in the body of an exposed organism over a period of time. The dose can be partitioned into three components: internal dose and biologically effective dose. The internal dose is the amount of a contaminant that is absorbed into the body over a given time, and the biologically effective dose is the amount of contaminant or its metabolites that has interacted with a target site over a given period so as to alter a physiologic function. A third component is the dose reaching the target tissue, whether or not it produces a biologic effect. It should be noted that absorption includes any process in which the agent crosses body surfaces or membranes and reaches the bloodstream. Generally, the concentration of a chemical in an environmental medium is evaluated for calculations of the dose; however, in cases of exposure to physical agents, particles, and fibers, attributes other than simple concentration, such as particle surface area, flow length and diameter, and ultraviolet radiation at a given wavelength, are measured. The administered quantity can be further defined in several terms, including amount of agent per unit body weight, amount of agent per body surface area, and amount of agent per region of the lung per minute. In summary, exposure assessment is the measurement or estimation of the magnitude, frequency, duration, and route of exposure as well as a description of the size and nature of the exposed population.
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ROUTES OF EXPOSURE

The route of exposure affects the extent of absorption and therefore the absorbed dose. The main sites of absorption are the lungs, the skin, and gastrointestinal tract.

Inhalation exposure

Inhalation is the most important route of entry of many biologic and chemical agents into the body. Inhalation exposure per event is estimated based on the duration of each event, the inhalation rate of the exposed individual during the event, and the concentration of contaminant in the inspired air. Inhalation exposure occurs from breathing ambient air (community air pollution), indoor air (indoor air pollution), and contaminated air in the work environment. Airborne contaminants can be present in the gaseous phase (gases and vapors), liquid phase (droplets), and solid phase (particulates and fibers). Uptake of gases and vapors depends on concentration and relative solubilities of the agent in water and lipids, and deposits of particulates in the respiratory tract depends on size, shape, and density of the material. First factors influencing uptake of gases and particulates include age, weight, sex, race, disease state, and respiratory rate.

Dermal exposure

Dermal exposure is determined by the concentration of hazardous substance in a contaminated medium that is contacted, the extent of contact, and the duration of such contact. Factors influencing dermal absorption of chemicals include molecular weight of the compound, its solubility in lipids, presence of other compounds that might facilitate passage of a chemical through skin, and the permeability of the skin. Dermal exposure takes place during swimming or bathing in contaminated water, skin contact with the soil, and various industrial operations.

Ingestion exposure

Exposures due to ingestion of contaminated food (drink) can be estimated as the product of contaminant concentration in the consumed food or drink and the amount of food or drink consumed per day. Daily ingestion exposure estimates are calculated in the same manner, regardless of the type of ingested food. In adults, ingestion exposure is mainly due to consumption of contaminated food and drinks, but in children, contaminated soil should also be taken into consideration. Children consume between 50 and 100 mg soil per day, but this amount may exceed 1000 mg in children with pica.

Eye exposure

Eye exposure results from accidental contact of the eyes with biologic, chemical, and physical agents. The eyes are very sensitive to these insults and can be affected by exposure to a minute amount of an agent. For example, the cornea must remain transparent; hence irritants causing scarring, a normal process of the body with little adverse effect in other organs, can destroy the function of the eye. Consequently, a small amount of an acid will affect elsewhere in the body can cause blindness. Another example is cupricer's pupil, which is mydriasis caused by operating machinery in confined spaces containing jimson weed (Datura stramonium), from which hyoscymine and related substances reach the eye to cause dilatation of the pupils.18 The significant effects on the eyes of the minute amounts of irritants present in food, such as those released from carrots and capsicum, the hot extract of pepper, are well known. On the other hand, there is a dearth of information on chemicals that can be absorbed through the eyes in amounts enough to induce systemic poisoning without causing damage to the eye itself. Examples include fluorosilicate, which caused convulsions and death without affecting the eyes of rabbits, and p-phenylene diamine, a major ingredient in Lung Lure (before regulation of chemicals used in cosmetics), which has been reported to cause a fatality after application to the eyelids.19 It should be noted that many physical agents, such as ultraviolet radiation, also have direct effects on the eye.20

Parenteral exposure

Parenteral exposure is usually encountered in two scenarios: bites and stings by animals and occupational exposure among health professionals and veterinarians from cuts and bites by sharp instruments such as needles contaminated with blood pathogens. Nonoccupational infections with human immunodeficiency virus (HIV) among health professionals is well documented. In 1988 the Centers for Disease Control reported 26 cases of HIV infections in health care workers who had percutaneous, nonintact skin, or mucous membrane exposures to HIV.21

Obviously, age, sex, race, and activity influence the average inhalation rate, the rate of food and water intake, the body area subject to dermal exposure, and the types of food consumed, all of which can affect the level of exposure actually experienced. It is also essential that assessment of exposure include all possible routes of entry of the agent into the body for all environmental media, that is, air, food, water, and soil.

PRINCIPLES OF EXPOSURE ASSESSMENT

Exposures are generally classified into two major categories: acute and chronic exposures. Acute exposure is usually associated with exposure to a single dose over a short period. Acute exposures can involve a single chemical or multiple chemicals, and the health effects associated with the exposure become apparent very quickly. Acute exposures generally last less than 24 hours. Long-term exposure, on the other hand, involves receiving a dose at frequencies over a longer period, which may range from hours to days to months or years. Health effects after long-term exposure are a function of the route of exposure and accumulation and metabolism of the chemical. Long-term exposures are usually of longer duration and low-level concentration. Exposures may be multiple and overlapping, and the
overall biologic response can be influenced by other environmental exposures, which may act synergistically or antagonistically. Selection of agents to be measured

Environmental and occupational epidemiologic investigations performed to develop dose-response relationships have improved significantly during the past four decades because of advances in the fields of biostatistics, epidemiology, industrial hygiene, and medicine. Earlier epidemiologic studies focused attention on measurement of disease outcomes, and little attention was paid to assessment of exposure. In these studies, duration of employment and questionnaire responses administered to study participants about their exposure were used instead of actual evaluation of environmental exposures. Other times, study participants were sorted into exposure categories that were based solely on their job titles. These practices resulted in inadequate descriptions of exposure and in many cases erroneous assignment of exposure categories.

Current studies require the participation of industrial hygienists or environmental engineers. These environmental scientists are trained not only to recognize the health effects of the various agents that may be present in the environment but also to measure the various attributes of the agent that are associated with the particular health effect under investigation. They are able to collect the right background and field information to answer the typical questions of where, what, how, and when exposure to measure. The collected information is subsequently used to identify and quantify the exposure of each study participant and to develop uniform exposure categories that cover a range adequate for meaningful distinction among groups.

The National Research Council has established a hierarchy of exposure data that can be used in the development of sampling strategy. In this scheme, seven categories are included, of which direct personal monitoring represents the best approximation to actual exposure. Other categories in the hierarchy are considered to be indirect measurements and are subdivided into information derived from quantification of concentration of the agent in the microenvironment (area or ambient measurement) and information that does not use quantitative estimates of exposure but rather surrogates of exposure, such as site of residence. The categories in the hierarchy are presented in Table 4-1.

It should be noted that often environmental conditions in which the airborne concentration of the agent is very low may arise. Reliance on personal sampling schemes would be self-defeating because of the very small volume of air that can be collected with battery-operated personal sampling pumps. This small volume results in the collection of a very minute amount of the contaminant that is below the limit of detection of the analytic procedure. Under these conditions, area samplers capable of collecting large volumes of air samples are used. The partial loss of information due to collection of samples by area samplers is compensated for by the large volume of air samples and the large amounts that can be collected of the agent, adequate for subsequent physical and chemical analysis. This change from personal to area samples represents a shift from category 1 to category 2 in Table 4-1.

Selection of an attribute of the agent to be measured

Perhaps no other category of toxic substances exhibits the degree of interdependence of physical characteristics and toxicity as aerosols. Some of the important properties of aerosols include shape, size, surface area, density, and chemical composition of the parent material. These factors affect site of deposition in the lung, interaction with lung tissue, solubility is lung fluids, and durability as well as persistence in lung tissue. A case in point is mineral fibers in general and asbestos fibers in particular. Stanton and Wrench showed that fiber toxicity is related to fiber length and diameter, whereby long (more than 10 μm) and thin (less than 0.5 μm) fibers are the most toxic. The mineral type of asbestos affects not only the shape and size of fibers but also their durability in lung tissue and consequently phagocytic and cyscinocytic potential. Another example is silica dust, the fibrogenicity of which is related to whether the dust is amorphous or crystalline form, the type of crystalline structure, and particle size. Thus, in the case of asbestos, the attributes of interest that should be taken into consideration are asbestos type and concentration of fibers in the various length and diameter categories. For silica dust, it is essential to measure the concentration of the fine fraction of the dust known as respirable dust (the dust fraction deposited in the unenciliated part of the lung, that is, the gas-exchange compartment); to know whether it is amorphous or crystalline; and, in the case of the matter, to determine the exact crystalline form, that is, quartz, cristobalite, or tridymite.
Evaluation of exposures to gases and vapors is relatively simple in comparison to sampling of particulates. Because the gas or vapor is present in molecular form, we have only one degree of freedom, that is, determination of the concentration or the number of molecules per unit volume. Some gases or vapors exist in more than one form, or isomer (that is, the compound exists in two or more forms that are identical with respect to percentage composition but differ as to the position of the atoms within the molecule). If the chemical and toxic potentials of the isomers are different, the exposure to each isomer should be determined.

For example, toluene diisocyanate (TDI) is a chemical with two isomers, 2,4-TDI and 2,6-TDI. When the isomeric composition of airborne TDI was measured in the polyurethane foam industry, it was found that there is a large increase in the amount of airborne 2,4-TDI relative to 2,4,6-TDI as compared with the starting material. The magnitude of increase depended on the stage of production. The finding is consistent with the lower reactivity of 2,4,6-TDI, although it has often been assumed that the industrial environment consists primarily of the 2,4 isomer or a mixture of the 2, 4 and 2, 6 isomers in the same ratio as that of the starting material. The significance of these findings becomes apparent in light of the fact that both the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) and American Conference of Government Industrial Hygienists' (ACGIH) threshold limit value (TLV) are for 2,4-TDI only. Further, the dose-response relationships that these standards are based on were developed with use of air-sampling methods that underestimated total TDI exposure because of the lower reactivity of 2,4-TDI.

Use of markers and surrogates of exposure

Markers and surrogates of exposure are new names applied to practices that have been used extensively in the past by many investigators. These practices are undergoing a process of redefinition in terms of applicability and use. In 1938 Dreessen and his colleagues described asbestos exposure among 541 employees in asbestos textile plants in terms of total number of airborne particles, because at that time there was no known method for measuring airborne asbestos. Thus the total concentration of all types of airborne particulates was used as a surrogate for asbestos exposure. More recent epidemiologic investigations of the health effects of asbestos had to consider that part of the information on historic exposure was described in terms of total particles and available contemporary information was presented in terms of airborne asbestos fibers. To solve this problem, studies to estimate the relationship between total concentration of airborne particulates and airborne asbestos fibers were done.

Another use of markers and surrogates is to describe exposure to complex mixtures in which either the active and causative agent has not been identified or an infinitesimal number of agents may be present at the same time. An example of the first case is cotton dust,* and typical examples of the second are diesel exhaust and cigarette smoke, in which more than 3800 compounds have been identified. Markers are used to describe relative levels of exposure to a complex mixture when the underlying assumption is that if exposure to a mixture is related to the health effects, there should be a parallel correlation between exposure to the marker and exposure to the mixture. Markers of cigarette smoke include respirable particulates, carbon monoxide, and nicotine.

Use of biologic markers

Biologic markers are biologic materials obtained from humans exposed to contaminated media (see Chapter 63). A marker can be either an exogenous substance that indicates exposure, such as a heavy metal; a biochemical change that would indicate potential health effects; or variation in a vital body function, such as metabolism, that would be associated with exposure. Biologic markers constitute one of the most important and rapidly evolving areas in assessment of exposure. The National Research Council has described three types of biomarkers: markers of exposure, markers of effects, and markers of susceptibility. In a recent monograph by Huikka et al., Biological Markers in Epidemiology, the authors classified the types of biomarkers as internal dose markers, biologically effective dose markers, biologic response markers, markers of subclinical disease, and susceptibility markers. On the other hand, biologic markers are associated with a very wide margin of variability. The factors influencing this variability include individual variability, interactive effects of exposure, diet, and diurnal variation. Therefore, investigators should be aware of the possible misuse of these markers. For example, elevated alcohol concentration in the blood is used, however, by law-enforcement agencies as a test for neurotoxicity or intoxication that impairs driving ability. Obviously, different individuals with identical internal doses of alcohol vary widely in terms of effects on driving ability. An important development in the field of biologic markers is the publication of 37 biologic exposure indices by ACGIH. Because of the advantages of breath analysis, which include immediate results, assessment of exposures by all routes, its noninvasive nature, and acceptability by workers, the ACGIH is also considering the publication of biologic exposure indices for volatile compounds.

TECHNICAL TERMS AND UNITS

In this section some of the important technical terms and units encountered during assessment of exposure are introduced and discussed. They are related to expression of air ventilation in buildings as well as expression of concentration of contaminants in air, food, and water.

Air ventilation

Cubic feet per minute (CFM) of outdoor air. The CFM is the unit of air flow usually specified in American
Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards. 1 The CPM of outdoor air per square foot. The CPM of outdoor air per square foot is another way of specifying ventilation rate of outdoor air. It is expressed in terms of the net available area, not the gross area of the building. This unit is also used in the ASHRAE standard. 2

Air changes per hour. Air changes per hour is the conventional way of expressing the total actual ventilation on a specific space. It is equal to the ventilation air flow rate in CPM divided by the volume of ventilated space in cubic feet; however, it can also be used to express air changes per hour of outdoor air.

Airborne contaminants

Concentration of gases and vapors. A gas is a substance that is in the gaseous phase at normal temperature and pressure (NTP). On the other hand, a vapor is the gaseous phase of a material that is usually a solid or a liquid at NTP. The concentration can be expressed as parts of contaminants per million parts of air by volume (ppm) or in terms of weight of contaminant (in milligrams) per unit volume of air (in cubic meters), that is, milligrams per cubic meter.

Concentration of particles. Concentration of particles is usually expressed in weight of dust (milligrams or micrograms) per unit volume of air that is, milligrams per cubic meter. Under some circumstances, the concentration of dust that can be tolerated is very low, such as expression of concentration of particles in clean rooms used in electronics and the space industry or the case of asbestos fibers in indoor air. Under these circumstances, concentration is expressed in terms of number of particles per liter or fibers per milliliter of air, for example fibers per milliliter in the case of asbestos.

Waterborne contaminants

Although water that can be consumed without concern for adverse health effects is referred to as potable water, the term does not mean that it has to taste good. On the other hand, palatable water may taste good but is not necessarily safe. Community water systems are designed to provide water that is both potable and palatable. Different substances and contaminants that may be present in water are classified as follows:

Suspended, colloidal, and dissolved solids. Suspended solids are solids large enough to settle out of water. They can be removed by sedimentation or filtration. Dissolved solids are those that are in solution; that is, they are homogeneously dispersed in the water. They can be removed from water by extraction, precipitation, or distillation. Colloidal solids are in a size that ranges between suspended and dissolved solids. They are hard to remove from water but can be removed by filtration through small-pore filters and by centrifugation. Suspended and colloidal solids, including clay silt, organic material, and plankton, cause turbidity in water. The unit of measurement is turbidity units (TU).

Color. Color in water can be due to the presence of dissolved or colloidal solids. Excessive amounts of algae and other microorganisms also affects color.

Taste and odor. Taste and odor in water can be caused by dissolved gases and inorganic and organic compounds. Consumers expect water to be odor and taste-free.

Expression of concentration. The expression of concentration of various dissolved substances such as chlorides, fluorides, and sulfates is usually presented in milligrams of solids per liter of water. Because the density of water is equal to unity and because the dissolved salts at the concentrations encountered in surface water do not significantly affect water density, it can be shown that the concentration in milligrams per liter is numerically equal to the concentration expressed as parts of the contaminant per million parts of water on a weight basis. It should be noted that this is not true in the case of air.

ASSESSMENT OF AIRBORNE EXPOSURE

During sampling, a sufficient amount of the contaminant must be collected to perform subsequent qualitative and quantitative analytical procedures. The amount collected is proportional to the airborne concentration, sampling flow rate, and duration of sampling. Sampling can be performed to obtain either area or personal samples. The selection of the sampling method depends primarily on the airborne contaminant, the purpose of the survey, and subsequent sample analysis.

Before any sampling program is undertaken, it must be ascertained whether a particular situation is covered by statutory requirements of a federal, state, or local regulatory agency. If the situation is regulated, the decision to depart from the official regulatory procedure is a major one, because the individual then carries the burden of proving the equivalency of the selected unofficial method. Sampling and analytic techniques are described in adequate detail in several publications by the Environmental Protection Agency (EPA) and the National Institutes for Occupational Safety and Health (NIOSH). Comprehensive descriptions of air sampling equipment and analytic methods available at the present time are presented in several recent publications.*

*References 1, 11, 12, 14, 18, 27.

Aerosol sampling

Samples of particles may be collected by a variety of techniques, including filtration, electrometric precipitation, and impaction. Particle collection can be obtained with or without size separation. Collection without size separation is used to obtain total suspended particulate matter for subsequent gravimetric, chemical, or physical analysis. Collection with size segregation is used to determine the particle...
size distribution of airborne particles or a specific fraction of the dust cloud, such as the inspirable particulate mass, thoracic particulate mass, and respirable particulate mass fraction.  

Sampling of gases and vapors
Sampling of gases and vapors can be conducted to obtain grab, intermittent, or continuous samples. Each sampling procedure provides data representing a range of averaging times. Grab samples can be collected with gas-sampling bags, evacuated bottles, gas syringes, and gas-detector tubes. Intermittent samples can be obtained by absorption of the gases in liquid media contained in bubblers and impingers or absorption of gases on solid media such as charcoal and silica gel.

A new technique that is becoming very popular is passive dosimetry, such as badges (analogous to radiation badges). Gases and vapors are allowed to diffuse into the collection medium of the dosimeter; therefore, the use of an air-moving device or an air pump is not needed. Another category is the direct-reading instruments or meters used extensively in field evaluations. Generally, they can be operated intermittently or in a continuous mode and provide real-time sampling and readout. These instruments are based on some physical or physicochemical property of the gas or vapor. They include ultraviolet/visible photometry, infrared analysis, chemiluminescence, combustion, electrical conductivity, electrochemical analysis, Coulometry, flame ionization, gas chromatography, and photolization.  

A major disadvantage of these types of instruments is their high cost.

ASSESSMENT OF WATERBORNE EXPOSURE
The water environment is composed of two interrelated phases: groundwater and surface water. Because of the close interrelationship, the complete assessment of impact involves consideration of both groundwater and surface water. Groundwater contamination is often harmful, and the source is sometimes very difficult to locate. Groundwater is contaminated mainly from septic tanks, sewage wells, and leachates from waste disposal. The most frightening aspect of groundwater pollution is that by the time the problem is discovered, it is generally too late to do anything about it.  

The public health hazards posed by surface water pollution depend on many factors, including the ultimate use of water. A surface water pollution source generally is located above ground, which often leads to recognition of the presence of a problem before serious health or environmental effects are observed. Physical, chemical, and biologic characteristics of water should be taken into consideration in assessment of waterborne exposure. Physical properties of water include turbidity, color, temperature, sediment, and floating solids. Chemical pollution of the water environment is mainly due to dissolved solids, phosphate, pesticides, petrochemicals, heavy metals, and other toxic substances. Biologic characteristics of water include bacteria, viruses, parasites, fungi, and other organisms. Adults usually drink about 2 L of water per day.

EXPOSURE LIMITS
A national consensus of safe working standards and regulatory standards have been developed by a variety of national organizations and governmental agencies. These standards, together with exposure assessment, are used to render judgments regarding the safety of environmental conditions. Therefore, the most useful information is obtained from quantities of data that can be related to the threshold exposure that may result in a health effect. A threshold is defined as the relationship of the lowest detectable level of a biologic or toxic response of the host to a specific concentration or dose of an agent, below which no toxic effect occurs. The following discussion focuses on several important types of standards for safe exposure.

Occupational standards
ACGIH threshold limit values. The ACGIH has established the TLVs as guidelines for the control of health hazards in the work environment. TLVs are established on the basis of unconsciousness, irritation, or other forms of toxicity. TLVs are presented in two ways: time-weighted average concentrations and short-term exposure limits of airborne chemicals that would be acceptable for an 8-hour day, 40 hours per week, to which nearly all workers may be repeatedly exposed, day after day, for a working lifetime without suffering any adverse health effects. Each year the ACGIH updates and publishes a list of TLVs and biologic exposure indices.  

OSHA permissible exposure limits. The 1970 Occupational Safety and Health Act established two new governmental organizations: OSHA, which is the policing and enforcing arm of the act, and NIOSH, which represents the research arm of the act. OSHA publishes health standards known as PELs and short-term exposure limits based on recommendations by NIOSH. They are conceptually similar to TLVs but differ in some specific allowable concentrations because of the time-consuming process required for the establishment of each new standard. As a result, PELs established by OSHA are not always the same as TLVs published by ACGIH. Traditionally many of the ACGIH limits have been more conservative than those established by OSHA, because of flexibility in the process of establishing and updating the TLVs. The PELs are enforceable standards under the Occupational Safety and Health Act.  

NIOSH recommended exposure limits. NIOSH develops and periodically revises recommendations for limits of exposure to hazardous substances or conditions in the workplace. These recommended exposure limits (RELS) are published and transmitted to OSHA for use in promulgating the PELs.  

Another category established by NIOSH is that representing conditions that are immediately dangerous to life or health (IDLH). An IDLH condition means an atmospheric
concentration of any toxic, corrosive, or asphyxiant substance that poses an immediate threat to life or would interfere with an individual's ability to escape from a dangerous atmosphere. In other words, IDLH can be defined as a concentration representing the maximal level of a pollutant from which an individual could escape within 30 minutes without escape-impairing symptoms or irreversible health effects. IDLH conditions most generally arise in emergency situations, thus making essential training for situations in which emergencies may arise. NIOSH's other responsibilities include development of methods for assessment of exposure, training of personnel in the field of occupational health, and, finally, publishing of information on occupational hazard assessments and special hazard evaluations and reviews.

Oxygen deficiency. The normal oxygen content of the air at sea level is 21%. Oxygen deficiency is defined as any concentration below 19.5%. A decrease in oxygen concentration to 16% can result in mental impairment, and the decrease of oxygen concentration below 16% can result in unconsciousness and death. Monitoring of the oxygen concentration in ambient air is required before entry into a confined space or unknown area. Because the pressure of oxygen also depends on air pressure (760 mm Hg at sea level), different criteria are used at high altitudes. (See Chapter 52.)

Community standards

Community air pollution. Although air-pollution abatement standards were enacted in many American cities, such as Chicago, as early as 1881, significant regulations at the federal level were promulgated only during the last three decades. This change was a result of social interest and national reaction to the rapid deterioration of environmental quality on all fronts, that is, air, water, and soil. As a result, the National Air Pollution Control Administration was dissolved and air pollution control functions, together with other environmental control responsibilities, were transferred to the EPA, an independent federal agency created by an executive order of the president.

National ambient air quality standards. Development of air-quality standards for ambient air assumes that some level of contamination is permissible but low enough so that it does not cause significant adverse health effects. Under the 1967 Air Quality Act and subsequent amendments of the Clean Air Act in 1970, 1977, and 1990, the federal government was charged with the responsibility of developing uniform National Ambient Air Quality Standards (NAAQS). These standards included primary standards to protect the health of the public and secondary standards to protect public welfare. The Air Quality Act also specified that promulgation of NAAQS must be preceded by the publication of Air Quality Criteria. These criteria are issued in document form and summarize all relevant scientific information on the health and welfare of individual pollutants so that air-quality standards are supported by good scientific evidence. NAAQS are not instantaneous standards but refer to average exposure over a period of hours to a year. NAAQS, averaging times, and recommended measurement methods are presented in Table 4-2.23

Indoor air pollution. The enforcement of OSHA's safety and health standards in the work environment is pos-

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**Table 4-2. National ambient air quality standards**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Averaging time</th>
<th>Primary standard</th>
<th>Secondary standard</th>
<th>Measurement method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>6 hr</td>
<td>10 mg/m³ (9 ppm)</td>
<td>Same</td>
<td>Non-dispersive infrared spectrophotometry</td>
</tr>
<tr>
<td></td>
<td>1 hr</td>
<td>40 mg/m³ (33 ppm)</td>
<td>Same</td>
<td></td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>Annual average</td>
<td>100 μg/m³ (0.05 ppm)</td>
<td>Same</td>
<td>Colorimetry using Saltzman method or equivalent</td>
</tr>
<tr>
<td></td>
<td>Annual average</td>
<td>50 μg/m³ (0.03 ppm)</td>
<td>Same</td>
<td>Pararosaniline method or equivalent</td>
</tr>
<tr>
<td></td>
<td>24 hr</td>
<td>365 μg/m³ (0.14 ppm)</td>
<td>Same</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 hr</td>
<td>1300 μg/m³ (0.5 ppm)</td>
<td>Same</td>
<td>Size-selective samplers</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>Annual average</td>
<td>50 μg/m³</td>
<td>Same</td>
<td>Flame ionization detector using gas chromatography</td>
</tr>
<tr>
<td></td>
<td>Annual average</td>
<td>160 μg/m³ (0.24 ppm)</td>
<td>Same</td>
<td>Chlorheximine method or equivalent</td>
</tr>
<tr>
<td></td>
<td>3 hr</td>
<td>255 μg/m³ (0.12 ppm)</td>
<td>Same</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6-9 AM)</td>
<td>50 μg/m³</td>
<td>Same</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 hr</td>
<td>1.5 μg/m³</td>
<td>Same</td>
<td>Atomic absorption</td>
</tr>
</tbody>
</table>

*Standards other than those based on the annual average are not to be extended more than once a year.*
sible because of the clear-cut relationship between the industrial processes and the concentrations of air-borne contaminants. Moreover, the exposed population is composed of healthy adults who are to some extent willing to accept the risks associated with the justified exposure for 8 hours per day, provided that levels are below the OSHA PEL. Unfortunately, such is not the case with indoor air-quality problems that occur at home and in offices, schools, and public buildings from indoor and outdoor sources. The exposed population covers the entire health spectrum, including infants, the infirm, pregnant women, and the elderly.

In addition, persons with allergies or diseases of the heart and lungs are more susceptible to these problems. Hence, the development and enforcement of comprehensive indoor air-quality standards are virtually impossible. The OSHA PEL, ACGIH TLV, and NIOSH REL are derived for the industrial setting and should not be used as evaluation criteria for indoor air quality. Thus the only standards that seem to be applicable at the present time are those published by ASHRAE, derived from recommendations by the World Health Organization. Building owners and managers concerned about the possibility of existence of indoor air-quality problems in their property may consult the Guide for Building Owners and Facility Managers published by the EPA.

Soil and food contamination. It is difficult to identify all sources of exposure to any given case. Soil ingestion may be important for some small children, but it is unusual for soil to be ingested directly by adults. The Food and Drug Administration (FDA) Market Basket Survey consists of samples of groceries that include 234 different food items sampled four times each year in three cities in each of four regions. Comparisons are made between the measured values and acceptable daily intakes (ADI) established for individual contaminants. ADIs are established by the FDA as the maximum amount of a chemical that can be safely ingested without substantially increasing an individual's lifetime risk of illness from that chemical.

Water contamination. Contamination of water bodies supplying drinking water to the general public led to laws initially passed by state legislatures and later by Congress, such as the Federal Water Pollution Control Act of 1948, that required intervention by the U.S. Public Health Service and subsequently by the EPA to ensure the safety of the nation's water supply. The National Safe Drinking Water Act of 1974 is designed to achieve uniform safety and quality of drinking water by identifying contaminants and establishing maximum acceptable levels for the contaminates. The major provisions of the act establish primary regulations for protection of public health and secondary regulations that are related to taste, odor, and appearance of drinking water. National revised primary drinking-water regulations—maximum contaminant levels and secondary maximum contaminant levels published by EPA in 1992—are presented in Tables 4-3 and 4-4, respectively.

### Table 4.3. National primary drinking water regulations, U.S. EPA, 1992

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Maximum contaminant level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>0.05 mg/L</td>
</tr>
<tr>
<td>Barium</td>
<td>2 mg/L</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.005 mg/L</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.1 mg/L</td>
</tr>
<tr>
<td>Fluoride</td>
<td>4 mg/L</td>
</tr>
<tr>
<td>Lead</td>
<td>0.05 mg/L</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.002 mg/L</td>
</tr>
<tr>
<td>Nitrate as N</td>
<td>10 mg/L</td>
</tr>
<tr>
<td>Nitrates as N</td>
<td>1 mg/L</td>
</tr>
<tr>
<td>Total nitrogen and nitrate</td>
<td>10 mg/L</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.05 mg/L</td>
</tr>
<tr>
<td>Suspended particulate matter (suspended particles smaller than 10 μm)</td>
<td>0.00000000 fibres/L</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>0.02 mg/L</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.005 mg/L</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>0.005 mg/L</td>
</tr>
<tr>
<td>Trichloroethene</td>
<td>0.005 mg/L</td>
</tr>
<tr>
<td>Ethybenzene</td>
<td>0.7 mg/L</td>
</tr>
<tr>
<td>Methylchloroethene</td>
<td>0.1 mg/L</td>
</tr>
<tr>
<td>Styrene</td>
<td>0.1 mg/L</td>
</tr>
<tr>
<td>Tetraethenehexyl</td>
<td>0.005 mg/L</td>
</tr>
<tr>
<td>Toluene</td>
<td>1 mg/L</td>
</tr>
<tr>
<td>1,2-Dichloroethane</td>
<td>0.006 mg/L</td>
</tr>
<tr>
<td>Pum-Dichloroethene</td>
<td>0.075 mg/L</td>
</tr>
<tr>
<td>1,1-Dichloroethene</td>
<td>0.007 mg/L</td>
</tr>
<tr>
<td>1,1,1-Trichloroethene</td>
<td>0.2 mg/L</td>
</tr>
<tr>
<td>1,2-Dichloroethene</td>
<td>0.005 mg/L</td>
</tr>
<tr>
<td>O-Chloroethene</td>
<td>0.6 mg/L</td>
</tr>
<tr>
<td>O-Chloroethene</td>
<td>0.6 mg/L</td>
</tr>
</tbody>
</table>

### Table 4.4. National secondary drinking-water regulations, U.S. EPA, 1992

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Maximum contaminant level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.2 mg/L</td>
</tr>
<tr>
<td>Chloride</td>
<td>258 mg/L</td>
</tr>
<tr>
<td>Color</td>
<td>15 mg/L per 1 L of water</td>
</tr>
<tr>
<td>Copper</td>
<td>4 mg/L</td>
</tr>
<tr>
<td>Corrosivity</td>
<td>nontoxic</td>
</tr>
<tr>
<td>Fluoride</td>
<td>2.0 mg/L</td>
</tr>
<tr>
<td>Fouling agents</td>
<td>0.5 mg/L</td>
</tr>
<tr>
<td>Iron</td>
<td>0.3 mg/L</td>
</tr>
<tr>
<td>Manganese</td>
<td>2.0 mg/L</td>
</tr>
<tr>
<td>Odor</td>
<td>3 threshold odor number</td>
</tr>
<tr>
<td>pH</td>
<td>6.5-8.5</td>
</tr>
<tr>
<td>Silver</td>
<td>0.1 mg/L</td>
</tr>
<tr>
<td>Sulfate</td>
<td>250 mg/L</td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>500 mg/L</td>
</tr>
<tr>
<td>Zinc</td>
<td>5 mg/L</td>
</tr>
</tbody>
</table>