Chapter 1

Introduction to Air Pollution Science

LEARNING OBJECTIVES

By the end of this chapter the reader will be able to:

- discuss natural phenomena that impact air quality
- discuss the impact of humans and their technologies on air quality
- identify three early writers who shaped current thought on the health effects of air pollution
- describe the three great air pollution disasters of the twentieth century and what groups of people were the most affected
- explain how epidemiology, toxicology, and basic laboratory research are all needed to understand the health effects of air pollution

CHAPTER OUTLINE

I. Introduction: History
II. The Great Air Pollution Disasters
III. Modern Air Pollution Issues
IV. Risks vs. Benefits Associated with Air Pollutant Producing Activities
V. Agencies Involved in Air Pollution Assessment and Control
VI. The Scope of Modern Air Pollution Science
VII. Summary of Major Points
VIII. Quiz and Problems
IX. Discussion Topics
References and Recommended Reading

I. INTRODUCTION: HISTORY

Air pollution has two histories, an early unrecorded one and a more recent recorded one. By examining these histories, one can gain a broad perspective on air pollution, including its trends, and the relationship between the evolution of human technology and air pollution exposures. History also allows us to understand the way our current ideas about air pollution and its hazards might have developed, and how our regulations and controls came about.

Early History and Natural Events

About 4 billion years ago in the *Hadean* era, the surface of the newly-formed Earth went through a violent period characterized by intense bombardment from meteorites, frequent volcanic eruptions, boiling seas, and extreme ultraviolet radiation exposure. These conditions would certainly have precluded the complex and varied plant and animal life as we now know it. During the following *Archaen* era (3.8 to 2.5 billion years ago), the Earth cooled, and life consisted of bacteria that flourished in an atmosphere believed to be devoid of oxygen, and therefore toxic to modern life. **Figure 1–1** depicts these and other geologic eras. Meteorological and geological processes along with any existing life forms have shaped the atmosphere throughout the Earth's history. Long before humans appeared, there were several periods of time that had large changes in the composition of the Earth's atmosphere.

Because early primitive life depended on an environment with little or no oxygen, the eventual rise of early photosynthetic (relating to use of radiant energy to create new compounds) plant life resulted in the emission of large quantities of a highly reactive, and therefore toxic air pollutant, oxygen (**Figure 1–2**). This period (the *Proterozoic* era) would have been catastrophic for many of the established life forms, even producing some total extinctions. Thus the Proterozoic era produced the first, and greatest, air pollution disaster. The new oxygen-rich atmosphere eventually stabilized with an oxygen content of about 20 percent, which led to the flourishing of more of the new forms of life. This life included complex plants and animals. The current oxygen content in the atmosphere is about 20.9 percent at sea level under dry conditions. Should the oxygen content increase to, say 30 percent, extensive uncontrollable fires would result. Combustible materials, such as wood and other organic materials, ignite easily and burn rapidly at high oxygen concentrations. Low oxygen levels, less than 15 percent, would threaten the existence of complex animal life. The abundant life we know today fortunately serves to stabilize our current atmosphere. As a result, atmospheric

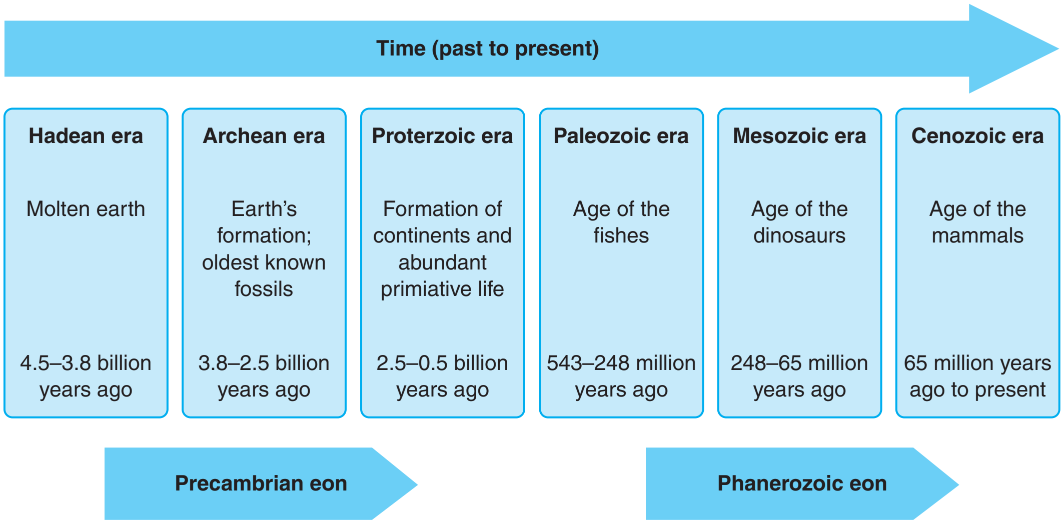

Figure 1–1 Geologic Time

Data from exhibits at the University of California Museum of Paleontology (http:/www.ucmp.berkeley.edu).
Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

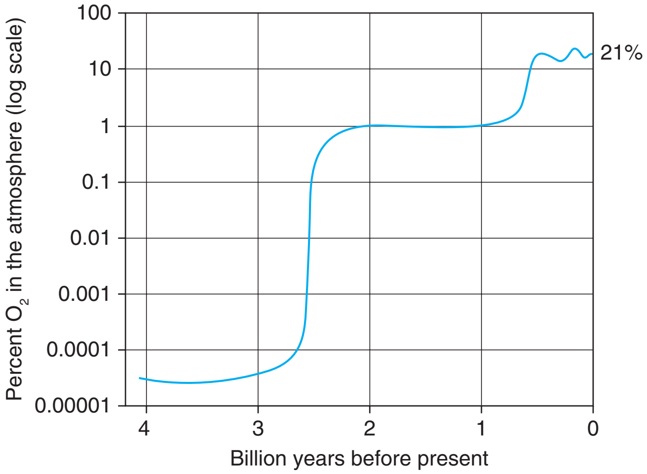

Figure 1–2 Modern view of the Earth's atmospheric oxygen over time. Fortunately, the current level of oxygen appears to be regulated by the interplay of several natural processes.
Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

oxygen levels have oscillated around the current level for hundreds of millions of years.

In addition to the impact of such long-term climate changes in the atmosphere, shorter-time events shape the atmosphere. Meteoric impacts and major volcanic eruptions, such as the one that formed Crater Lake in Oregon about 7,700 years ago, have significantly contaminated the global atmosphere periodically and even led to the extinction of some species. More recently, the eruption of Mount St. Helens in 1980 destroyed all nearby life and deposited ash thousands of kilometers (km) downwind (**Figure 1–3**). Natural fires, dust storms, additional meteoric impacts, and sporadic volcanic activity produced significant air pollution episodes. These natural events further shaped life, leading to a continuing series of extinctions and the emergence of new species. Natural changes in climate, including alternating cooling and warming eras, will continue to modify conditions that favor some species and make survival difficult for others. The role of humans and their associated air emissions on the evolution of climate is a topic of active current research (see Chapter 5).

Use of Fuels by Humans

Our human ancestors, who emerged only 4 to 6 million years ago, learned to use and eventually control fire.

Figure 1–3 The eruption of Mount St. Helens in Washington, 1980. CDC Public Health Image Library, ID # 4726 (http://phil.cdc.gov/phil/home.asp)

Archeologists have found hearths and fire-hardened wood spears that date to about 750,000 to 500,000 years BC. It is reasonable to assume that the early burning of organic fuels, such as wood, dried dung, and natural oils, would have generated combustion-related air contaminants in caves and other early dwellings. Evidence from observations of sinus-bone damage on ancient skulls and alterations in mummified Egyptian lung tissue is highly suggestive of the role of early indoor combustion products in producing disease. The acute effects of irritating smokes were certainly evident to the ancients. Whether or not they were able to link air quality to chronic health effects is another matter.

The eventual emergence of large population centers and associated primitive industrial processes would have led to community-level air pollution episodes that resulted from the burning of wood as a primary fuel. However, it was the introduction of a new fuel, coal, in the thirteenth century AD that stimulated several early writers to describe the adverse health effects of air pollutants. Coal usage and the rise of newer industrial activities, such as the smelting of metal ores, produced acidic, odorous, and irritating sulfur-containing pollutants which would have also contained toxic levels of metals such as lead and iron. The success of coal as a fuel and its widespread availability for industrial and domestic uses not only led to increasingly polluted air in outdoor and indoor environments, but it also served as the impetus that would eventually drive regulatory actions.

History of Attitudes and Perceptions

Our modern concepts about environmental contaminants can be traced in the writings of influential thinkers over the past 2,000 years. In ancient Greece, town controllers had the responsibility of maintaining environmental quality, including control of sources of odor such as that generated by rubbish and presumably other sources. Roman courts were involved in civil suits that were designed to protect wealthy suburbs from pollutants generated by a number of industrial processes. Greek and Roman physicians, including Hippocrates (c 460–375 BC), Galen (c 129–200 BC), and Pliny "The Elder" (c 23–79 AD) were prolific writers who helped establish the early foundations of medical practice, including descriptions of diseases (and treatments) related to the effects of natural and anthropogenic (human generated) toxicants. Both Hippocrates and Pliny were interested in occupational diseases because of the often extraordinary levels of industrial exposures and their adverse effects on the health of workers. The health effects of air pollutants were more evident in the most heavily exposed workers, such as those closest to the sources.

Alchemy, the predecessor of the science of chemistry, was practiced for about 1,000 years (c 750–1800 AD). In addition to dealing in secret elixirs and claims of the ability to turn lead into gold, alchemists worked hard to understand the causes of diseases, and to develop the equipment and laboratory methods that allowed modern chemistry to eventually emerge. Paracelsus (the pseudonym of Philippus Aureolus Theophrastus Bombastus von Hohenheim, 1493–1541 AD) was a noted Swiss alchemist and physician who revolutionized medical practice of his time by insisting that it must be based on *observation* and *experience* instead of just time-honored theory. This shift in thinking from relying on theory to drawing conclusions from data was revolutionary in its time. Paracelsus introduced substances such as sulfur, lead, arsenic, and iron into the realm of pharmaceutical chemistry, and he also studied occupational diseases extensively. As a result of his arduous work and fame, he is considered to be the father of the scientific discipline of toxicology, despite his persistent mystical beliefs and teachings. One of his greatest contributions to science was his remarkably astute observation related to the concept of *dose.* Paracelsus is quoted by Gallo (2008) thusly:

> "All substances are poisons; there is none which is not a poison. The right dose differentiates a poison from a remedy."

This proclamation is at the heart of modern toxicology. It is also the basis of many of our current regulations for air pollutants, where the goal is to set acceptable levels of specific air contaminants such that their doses do no significant harm to public health.

Alchemy, and its leading practitioners, not only shaped modern thought, but they also helped medicine and chemistry to become entwined in a manner that helped both to advance and mature. In parallel with these events during the period of alchemy, the discipline of toxicology was emerging from the early use of poisons. Plant extracts and toxic animal venoms were used for hunting, assassinations, and as deadly agents for use in warfare. Over thousands of years humans learned to fear toxic substances and to mistrust those who had the knowledge to use them. The use of poison gas in World War One (1914–1918) heightened any existing fear of air contaminants on the part of the public. Such fear, which generated a mistrust of new technological and chemical applications, persists in much of the population in our time. Although the concept of toxicity is well understood by the public, the role of dose in producing harm is not generally appreciated. This topic is elaborated in Dr. M. Alice Ottoboni's book, *The Dose Makes the Poison* (Ottoboni, 1997).

An early English environmental activist and writer, John Evelyn (1620–1706) courageously adopted a stern moral stance toward the effects of industrial air pollution. As a fellow of the *Royal Society of London* (established by Evelyn and others in 1662), and publisher of an influential booklet, *Fumifugium, or the Smoke of London Dissipated (together with some remedies humbly proposed)* he described, among other things, various means of control of air contaminant emissions. Although Evelyn was mainly concerned with the health of industrial workers, his basic idea of the vulnerability of workers can be seen as also applicable to sensitive groups of individuals in the general population. Evelyn's teachings, which were seen as revolutionary in his time, would fit well in our century. His message was strong, as is evident in a quote from *Fumifugium* (Evelyn, 1661):

> ". . . Inhabitants breathe nothing but an impure and thick Mist accompanied with a fuliginous and filthy vapor, which renders them obnox-

> ious to a thousand inconveniences, corrupting the Lungs . . .”

Although several other early thinkers and writers shaped the way in which air pollutants were perceived, two examples serve to demonstrate the evolution of thought. Bernardino Ramazzini (1633–1714), an Italian Professor of Medicine, described the diseases associated with the dangerous trades of his time. As a result of his work and writings, Ramazzini is generally considered to be the father of occupational medicine. A successful famous London surgeon, Percival Pott (1714–1788) is credited with linking chimney-sweep's scrotal cancers to their work; perhaps the first recorded observation of chemical carcinogenesis (the development of cancers).

Impact of the Industrial Revolution

By the time of the *Industrial Revolution,* which was marked by the introduction of steam-powered machinery in the mid-1800s, the linkages between severe air pollution and a variety of human diseases had been recognized. Coal- and oil-fired boilers not only ran power plants, ships, locomotives, and factories, but they also emitted large quantities of smoke that contained ash, partially-burned fuel solids, sulfur, oxides of nitrogen, and a variety of metals and organic gases and vapors (vapors are the gaseous states of volatile liquids). Legislation limiting atmospheric emissions and the establishment of governmental agencies that were intended to enforce regulations soon followed. Great Britain introduced what may be its first Public Health Act in 1848, which was followed by several other attempts to control air-pollutant emissions. In the United States, similar local ordinances were issued in the 1880s that were aimed at controlling smoke and ash emissions. However, the pressure for progress and its many associated benefits largely outweighed the enthusiasm for enforcement. Although the general nuisance and effects on health were recognized, little was done to effectively control air pollutants. It was the great air pollution disasters of the next century that changed the way in which the adverse effects of air pollution were perceived and addressed in our society.

II. THE GREAT AIR POLLUTION DISASTERS

The combined impact of widespread combustion emissions, cold weather, persistent fog, stagnant winds, and low air inversions (see Chapter 2 for a description of air inversions) led to sharp increases in deaths and illnesses in several affected communities. These events drastically changed the relatively tolerant attitudes toward air pollution. The three notable episodes in the first half of the twentieth century that were well documented became known as “*the great air pollution disasters,*” or “*the historic pollution episodes.*” These episodes made world-wide headlines, and they are still widely referred to by air pollution researchers and regulators. There were other air pollution episodes in the twentieth century as well, but they were less well publicized than the three major episodes that occurred in Europe and the United States of America.

Meuse River Valley, 1930

The first of the three historic air pollution episodes occurred in eastern Belgium in a river valley about 2½ km wide and 100 meters (m) deep. The Meuse River Valley was heavily industrialized with a variety of air pollutant sources including several electric power generating plants, over two dozen major factories, substantial railroad, truck and automobile traffic, and the domestic use of coal for heating homes (**Table 1–1**). A six-day period starting on December 1, 1930 had an unprecedented combination of low temperatures, fog, and low wind speeds. The fog droplets facilitated the conditions for a variety of chemical reactions in the air.

Table 1–1 Sources of air pollutants in the Meuse river valley in 1930.

Industry	*Transportation*	*Other*
Five coking operations	Railroads	Use of coal for domestic heating
Four large steel plants	Trucks	
Three metallurgical factories	Automobiles	
A fertilizer plant		
A sulfuric acid plant		
Four electric power plants		
Six glass works		
Three zinc plants		

Data from Clayton and Clayton (1978).

Cold weather increased the burning of coal for home heating. The low wind speed prevented the dispersal of the air pollutants that had accumulated in the valley. The buildup of a variety of gaseous and particulate air pollutants soon produced a large spike in excess human deaths and illnesses, along with a substantial loss of cattle. In a two-day period, December 4 and 5, sixty-three excess deaths (about 10 times the expected number), and 6,000 illnesses were observed. Most of the deaths were in two groups, the elderly and persons with preexisting heart and lung diseases, but others were also affected. Although concurrent air concentration measurements were not made, subsequent estimates by scientists indicated that high levels of particles in the respirable size range, significant sulfur dioxide levels, and associated acidic conditions all occurred. Notably, it was determined that the levels of individual air pollutants were probably not sufficient to produce the health problems; the effects of some unknown combination or combinations of meteorology and several air pollutants were likely causal. Professor J. Firket of the University of Liége was a member of an "enquiry" group that investigated the incident. In his report (Firket, 1936), he made a prophetic statement:

> ". . . the public services of London, e.g., might be faced with the responsibility of 3200 sudden deaths if such a phenomenon occurred there."

This is exactly what happened 16 years later in London (discussed later in this chapter), which probably brought no pleasure to the esteemed Professor Firket.

Donora Pennsylvania, 1948

The second notable incident took place October 25 to 31, 1948 in a river valley that included the communities of Donora and nearby Webster in southwestern Pennsylvania. The heavily industrialized Monongahela river valley, about 120 m deep, used soft coal as the main fuel for domestic and industrial establishments, and several major sources of air pollutants were present (**Table 1–2**). The episode began with persistent cool stagnant winds and heavy fog, described by Ashe (1952) as "unique in intensity as far back as history is available." The fog had the sharply irritating pungent odor of sulfur dioxide, and the ground-level visibility was so low (about 15 m) that it essentially brought traffic to a standstill. While only 1 to 2 deaths were expected during the time of the event, an astonishing 18 to 20 excess deaths were attributed to the episode. Although the exact number is debated, about 40 percent of the 15,000 residents was likely affected by the air pollutants; farm animals, especially chickens, were also apparently vulnerable. As in the 1930 Meuse River episode, the elderly and those with preexisting heart and lung diseases were most affected. The symptoms included eye and respiratory tract irritation, along with coughing and breathing difficulty. No air samples were taken at the time, but subsequent estimates indicated that sulfur dioxide levels as high as 2 ppm (5.5 mg/m^3 of air) and particle levels as high as 30 mg/m^3 (200 times the U.S. EPAs 2010 24-hour limit for particles with diameters under 10 μm in diameter) were present. Several other air pollutants including carbon monoxide, sulfuric acid, oxides of nitrogen, carbon, and several particulate metals were probably present in significantly elevated concentrations. Despite these high levels of individual pollutants, a subsequent U.S. Public Health Service study determined that a combination, rather than any individual pollutant, would be required to produce the adverse health effects.

Table 1–2 Sources of air pollutants affecting Donora, PA in 1948.

Industry	*Transportation*	*Other*
Four steel plants One zinc plant An electric power plant A glass company	Railroad, steamships, and traffic	Use of soft coal for fuel

Data from Clayton and Clayton (1978).

London, 1952

As predicted by Professor Firket in 1936, the most severe air pollution disaster in modern history took 3,000 to 4,000 lives of Londoners during a 4-day period, December 5 to 8, 1952. London lies in a wide valley of the Thames River, and it had a 1952 population of 8.6 million people. Again, meteorological conditions were unusually intense, with cool nearly stagnant air, heavy fog, and an air-pollutant trapping air-inversion layer at about 100 m above ground level. There was a rapid buildup of acidic soot-filled *smog* ("smog" is a compound word originally meaning smoke + fog) that interfered with traffic, and even caused pedestrians to become lost (**Figure 1–4**). Preexisting heart and/or lung disease,

Figure 1–4 Daytime visibility during the 1952 London air pollution episode.
Source: Photographer, Central Press; Hulton Archieves; Getty Images.

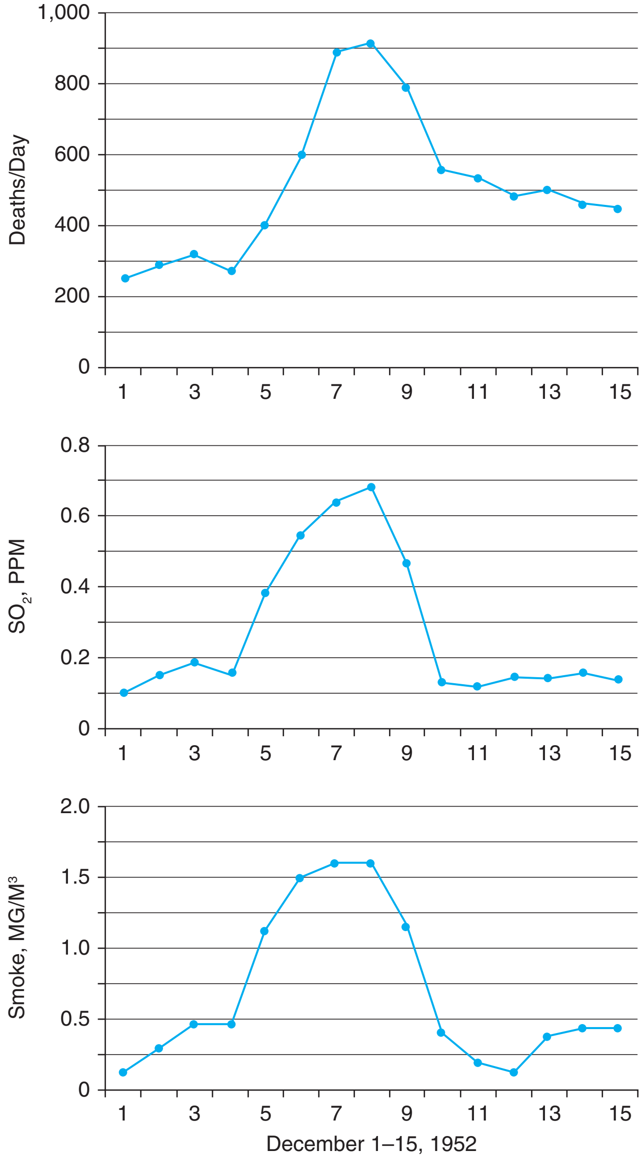

Figure 1–5 Data from the 1952 London air pollution episode; Top: daily deaths including normal deaths; Middle: city average sulfur dioxide concentrations; Bottom: City average smoke concentrations.
Data from Wilkins (1954).
Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

age 45 years and older, and infancy (under 1 year of age) were risk factors in 80 percent of the deaths. The causes of deaths included *pneumonia* (severe deep lung inflammation usually associated with infection), *bronchitis* (inflammation of the bronchial air passages, usually accompanied by fever, cough, and excess mucus production), and heart disease. Most illnesses occurred on the third and fourth days of the episode. The excess acute death rate was estimated to be between 2.6 and 5 times normal by various authors. A contributing factor could have been a prolonged influenza outbreak at the time.

In this case, air-sampling data were available (**Figure 1–5**). Prior to the episode, particle levels averaged a substantial 500 μg/m^3 of air, and sulfur dioxide levels averaged 0.15 ppm (which is not generally considered to be excessive). During the episode, particle levels averaged approximately 4,500 μg/m^3, and the sulfur dioxide level reached a substantial 1.3 ppm. The *British Smoke Shade* method was used to estimate particle levels based on the dark color of filter samples, so the actual levels of particles could have been higher. In addition to the observed health problems and excess deaths, soiling of metal surfaces and damage to clothing indicated that the smog was strongly acidic. This time, the use of soft coal (which has a high sulfur content) for heating homes was identified as a primary source of the air pollutants, although other sources were also present. As in the Meuse River Valley and Donora episodes, a combination of pollutants, rather than individual components, was the likely causal agent for the excess deaths and other damaging effects. Again, the London episode made world-wide news headlines, but this time the public impact was amplified because a large major modern city was severely afflicted. As a result, this episode triggered the British Clean Air Act of

Table 1–3 Summary of the historic air pollution episodes of the twentieth century, all of which occurred in geographies within a valley.

Location and Period	*Days Excess Deaths Occurred (Increase in Death Rate)*	*Contributing Pollutants Identified*				
		SO_2	*CO*	*Acids*	*Metals*	*Other*
Meuse Valley, Belgium Dec. 1–5, 1930	5–6 (10 fold)	Yes	Yes	Yes	Yes	Yes
Donora, PA, Oct. 27–31, 1948	3 (10 fold)	Yes	Yes	Yes	Yes	Yes
London Dec. 5–8, 1952	3–4 (2–5 fold)	Yes		Yes		Yes

Notes: SO_2 = Sulfur dioxide; CO = carbon monoxide. Data from Clayton and Clayton (1978).
Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

1956, which limited the use of soft coal for heating homes. It also set up the conditions for other earnest regulatory activities in Britain and other countries to control air pollution. Among these was the U.S. National Clean Air Act of 1963 and its subsequent amendments (http://www.epa.gov/air/caa/, accessed November 11, 2010).

Conclusions from the Three Air Pollution Disasters

All of these air pollution disasters had many factors in common. Severe, even unprecedented, meteorological conditions including persistent nearly stagnant air, intense fog, low-altitude air inversions, and cool to cold temperatures occurred simultaneously. Low temperatures led to increased use of domestic heating. Deaths were also seen to lag the beginning of the highest levels of air pollutants by two or more days. Those with preexisting heart and lung diseases, especially the elderly, were the most severely affected. Infants were also reported as being a susceptible group in the 1952 London episode. However, no single air pollutant could be blamed for the excess deaths and illnesses. An unknown combination of pollutants was more likely to have been responsible for the observed increases in deaths and illnesses. **Table 1–3** summarizes the episodes. Taken together, these incidents generated extraordinary public concern. The governmental responses led to an emphasis on research and legislation directed at both understanding the possible causes and at developing strategies for preventing future similar disasters. As previously noted, there were other episodes that were clearly less disastrous than the three great air pollution episodes, but they were also less influential.

III. MODERN AIR POLLUTION ISSUES

In the immediate period following the London episode of 1952, numerous epidemiologic studies and complimentary laboratory studies, with isolated cells, humans, and animals (see Chapter 9 and 10) were begun. Many of these initial studies were challenged on the basis of the use of unrealistically high concentrations of pollutants in laboratory animal and human clinical studies, or the failure to control for confounding variables (e.g., nonair-pollution factors that could influence health outcomes). However, the initial studies helped to:

- identify potentially harmful combinations and individual components of air pollutants;
- improve air sampling techniques;
- clarify the range of possible health effects associated with air pollutants;
- improve study designs; and
- demonstrate the combined value of *in vitro* (e.g., studies of biochemicals, isolated cells, and cell cultures), laboratory animal, human clinical, and epidemiology studies.

As a result: sampling and analysis methods for particles and gases in the air were improved; effects of pollutants on biochemical events in mammalian cells were delineated; new laboratory animal models and methods for exposing them to particles and gases were introduced; clinical research on resting and exercising human subjects were conducted; and several epidemiological studies that focused on comparing mortality (deaths) and morbidity (illnesses) in cities with different types and levels of air pollutants were conducted. The findings largely supported the conclusions made earlier from studying the great air pollution disasters, especially with respect to the vulnerable population groups, and the likely causal role (in deaths and illnesses) of combinations of air pollutants. Possibly the best way to summarize this early period of intense research is an observation from Dr. David Rall, who was the director of the U.S. National Institute of Environmental Health Sciences from 1971 to 1990. He observed that there is no better way to protect public health from environmental chemicals "than the combination of well conducted animal experiments and well conducted epidemiological experiments" (Rall, 1979). In a similar vein, Dr. Roger McClellan, former President of the Chemical Industry Institute of Toxicology and of the Lovelace Inhalation Toxicology Research Institute (now called the Lovelace Respiratory Research Institute), presented the concept of a three-leg stool (**Figure 1–6**), which illustrated the important role of a combination of mechanistic studies, laboratory animal toxicology studies, and human studies for protecting human health.

The large research effort eventually prompted the U.S. EPA to issue a series of National Ambient Air Quality Standards (NAAQS, pronounced "knacks"), which in 1997 tightened the acceptable limits for airborne particles, and introduced particle size-selective ranges (see Chapter 6). These actions stimulated considerable controversy, which was described in the book, *The Particulate Air Pollution Controversy: A Case Study and Lessons Learned* (Phalen, 2002). The controversy centered around several issues, including:

- the impact of the new standards on the cost of goods and services;
- the use of particle size and mass, rather than chemical composition for setting air standards;
- the use of new sophisticated epidemiologic models to estimate the health effects;
- the lack of confirmatory laboratory studies to establish cause and effect relationships among small fluctuations in particle levels and health; and
- the power of the U.S. EPA to independently establish the new air standards.

After a period of extensive litigation, the U.S. EPA was supported by the U.S. Supreme Court, and the new regulations had the force of law.

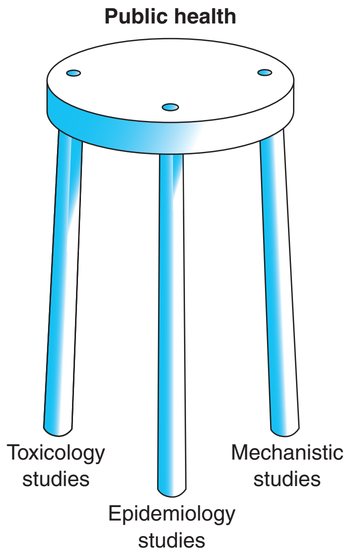

Figure 1–6 Three leg stool representing research on environmental chemical exposures conducted for the purpose of protecting public health.
Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

IV. RISKS VS. BENEFITS ASSOCIATED WITH AIR POLLUTANT PRODUCING ACTIVITIES

It is safe to say that all human behavior will produce some form of air pollution. In fact, the mere presence of humans, and their routine activities, inevitably contaminates the air (**Table 1–4**). On a larger scale, many essential productive activities such as farming, dairying, electric power generation, manufacturing, construction, spraying (e.g., paints and pesticides), and transportation all have their associated characteristic air contaminants (**Table 1–5**). Similarly, medical procedures, recreation, children's play, entertainment, hobbies, and other valued endeavors produce a large variety of associated environmental air contaminants. Thus, benefits accompany the potential adverse effects of sources of air pollution.

The foregoing examples make it clear that attempts to control air pollution can have counterbalancing effects (also called *tradeoffs*) on human health and welfare that must be seriously considered in regulatory actions. A monograph, *Risk versus Risk: Tradeoffs in Protecting Health and The Environment,* describes the issue in detail (Graham and Wiener, 1995). Accordingly,

Table 1–4 Humans as sources of air contaminants (examples only).

Factor	*Contaminant*	*Possible Effects*
Human presence	Shed skin cells (dander)	Transmission of virus, bacteria, fungi, and allergens
Exhaled air	Organic and inorganic gases, microorganisms	Spread of infectious diseases, and generation of odors
Clothing	Fibers, dyes, preservatives, etc.	Spread of potential airborne allergens
Use of sprays and powders	Cosmetics, disinfectants, cleansers, etc.	Respiratory tract irritation, allergic responses, and chemical poisoning
Cooking, cleaning, and other routine activities	Combustion products and resuspended dusts	Asthma and bronchitis exacerbation, and in rare cases initiation of lung diseases
Tobacco smoking, burning of candles, incense, and wood	Environmental tobacco smoke and other airborne combustion products	Asthma and bronchitis exacerbation, and possible initiation of lung diseases

when any specific activity is heavily regulated it must be modified, or sometimes even banned or replaced. This process can increase the cost of living, and even introduce new, as yet unstudied environmental contaminants. The main point is that, like the targeted air contaminants, regulatory activities can also have their potential hazards. Of course, the regulation of air contaminants is undeniably an essential activity, and some researchers point to the cost-effectiveness of modern regulations (e.g., Hall, et al., 1992). However, as people have to live with all of the consequences of regulations, good and bad, a thorough analysis and a responsible rate of implementation is necessary in order to prevent unacceptable unintended consequences. The modern trend is to balance the monetary costs of controls with the money saved from the expected health benefits. Even today, a thorough analysis of the regulation-related tradeoffs is not usually performed.

V. AGENCIES INVOLVED IN AIR POLLUTION ASSESSMENT AND CONTROL

The list of professional groups involved in air pollution assessment and control is large indeed: **Table 1–6**

Table 1–5 Some essential activities along with their emissions and benefits (examples only).

Activity	*Emissions*	*Benefits*
Agricultural practices (farming, dairying, and animal husbandry)	Sprays, ammonia, pollens, particles, microorganisms, dust, diesel exhaust, etc.	Affordable food and milk combats malnutrition and starvation, ammonia neutralizes air acidity
Electric power generation (except hydroelectric, wind, and nuclear, which have negligible air emissions)	Sulfur, metal-containing particles, and a variety of gases and vapors	Affordable electrical power is essential for food preservation, heating, air conditioning, lighting, and has a variety of other economic benefits
Transportation including cars trucks, ships, aircraft, etc.	Diesel and gasoline engine exhaust, tire and brake dusts, and partially-burned lubricants in exhaust	Personal and commercial transportation are essential for employment and the availability of food and other important products
Manufacturing and construction	A large variety of particles, gases, and vapors	Housing, roads, and numerous products are essential for maintaining a tolerable and healthful lifestyle

Table 1–6 Groups involved in assessing and controlling air pollutants (examples only).

Group	*Roles*
Researchers, including chemists, engineers, industrial hygenists, ecologists, and biomedical scientists	Measure air contaminants; evaluate their effects on humans, wild and domestic animals, and crops; and define which substances are high-priority for control
Engineers including automotive, chemical, electrical, and others	Design machinery and other systems; and measure air emissions
Health professionals, including physicians, public health specialists, and industrial hygienists	Evaluate health effects; develop treatments; solve practical problems; and provide advice to scientists, regulators, and patients
Governmental professionals	Identify issues of concern; provide public education; establish and enforce standards; and advise researchers and regulators
Environmentalists	Identify issues of concern; provide public education; and advise researchers and regulators
Health groups, related associations, and activist organizations	Identify issues of concern; provide public education; monitor problems and progress; raise money for research; and advise researchers and regulators

lists only a few types of such groups and their roles. In the United States, the Environmental Protection Agency (U.S. EPA) is responsible for setting ambient air standards to protect the general public. These standards are called the National Ambient Air Quality Standards (NAAQS). The NAAQS, which are intended to be revised every five years, include sulfur dioxide, particles (in various size ranges), carbon monoxide, ozone, nitrogen dioxide, and lead. Within the EPA the Office of Air and Radiation (OAR) deals with outdoor air quality, indoor air quality, toxic air pollutants (which differ from the NAAQS pollutants in that they expose the population less uniformly), and radiation. The OAR develops national programs, technical policies, and regulations for controlling air pollution and radiation exposure for the general public. The U.S. Centers for Disease Control and Prevention (CDC, http://www.cdc.gov, accessed November 11, 2010) develops and applies information on disease prevention and control, environmental health, health promotion, and health education, in order to improve the health of people in the United States. Within the CDC, the National Institute for Occupational Safety and Health (NIOSH, http://www.cdc.gov/niosh, accessed November 11, 2010) is responsible for research, education, and training geared toward promoting safe and healthful conditions for workers. In this role NIOSH develops information on safe air quality in workplaces. The Occupational Safety and Health Administration (OSHA, http://www.osha.gov, accessed November 11, 2010) is the enforcement agency for workplace air quality, among other factors (such as noise, vibration, and injuries) that relate to workers, safety and health. The Mine Safety and Health Administration (MSHA, http://www.msha.gov, accessed November 11, 2010) enforces compliance with safety and health standards for miners. As is evident, there is considerable overlap in the responsibilities of these governmental agencies, which are only examples of the total number that deal with air pollution in the United States. The European Union (EU), Canada, Japan, China, and other nations have similar regulatory and advisory structures that relate to air quality issues (Olesen, 2004; Chen et al., 2008). An influential professional association, the American Conference of Governmental Industrial Hygenists (ACGIH®), reviews its voluntary workplace air standard recommendations yearly and publishes them in their booklet "TLVs® and BEIs®" (ACGIH®, 2010). These recommendations, based strongly on animal studies and epidemiologic evidence, are not intended as regulations, but they are used worldwide for worker protection. Interestingly, ACGIH® does not always appear to consider the feasibility of meeting a recommended air quality recommendation.

A challenge for the long-term future is to develop uniform (also called *harmonized*) world-wide environmental standards without devastating productivity and prosperity. Such standards would presumably prevent large disparities in the exposures of workers and the general population throughout the world. Harmonized standards could also help prevent disputes over transboundary pollution (the movement across national boundaries), and discourage the practice of locating polluting industries in nations with lax air standards. As one might expect, harmonizing air standards is a complex and politically difficult effort that has large economic consequences.

VI. THE SCOPE OF MODERN AIR POLLUTION SCIENCE

All life that exists and performs its activities on the surface of the Earth is immersed in a finite sea of air. Similarly, non-living things, both natural and anthropogenic (made by humans), can affect and be affected by the air and the many substances contained therein. Even the planet itself, its overall climate, incident surface illumination, and exposure to ultraviolet radiation are influenced by air quality. These factors serve to establish the enormous scope of today's air pollution science, and thus the scope of this textbook. Essentially all of the scientific disciplines that are practiced today have roles to play in understanding, evaluating and, controlling air quality. In the following, a few examples of this broad involvement are listed.

Earth Science, Meteorology, and Climate

Earth science is the discipline that deals with the large picture. The scope includes the oceans and other bodies of water, the atmosphere, and the geologic Earth. The associated atmospheric scientists seek to understand the climate and the atmosphere through the development and use of surveillance, modeling, and data analysis technologies. Included in the Earth scientists' tools and interests are:

- Earth-observation satellites;
- aircraft, and Earth-based instrumentation;
- the use of supercomputers for modeling and understanding climate, weather, and air pollution sources and transport;
- analyses of trends in air quality; and
- defining the challenges, actions, and strategies associated with mitigating adverse effects.

The U.S. National Academies of Science (NAS, established in 1863 under President Abraham Lincoln) currently has several Earth science subdivisions (called "Program Units" or "Boards") that relate to air quality; they include:

- Agriculture and Natural Resources;
- Atmospheric Sciences and Climate;
- Chemical Sciences and Technology (which deals with energy production and use);
- Earth Sciences and Resources (which coordinates several research activities and provides information to policy makers); and
- Environmental Studies and Toxicology (which addresses air and water pollution and their impacts on human health and the environment).

Each subdivision produces reports published by the National Research Council (NRC), which was established in 1916 by the NAS to provide information for critical decision-making, formulating public policy, and important public education services, as well as stimulating the acquisition of new knowledge related to science, technology, and health. Hundreds of reports, many of which are available free online, have been published by the National Academies Press (http://www.nap.edu, accessed November 11, 2010). These reports are an invaluable resource for students as well as practicing professionals.

In addition, there are nearly 50 periodical scientific journals, and countless university research programs that deal with Earth sciences.

Ecology

The discipline of *ecology* deals with topics such as biodiversity, ecosystems, and associated environmental assessments. *Ecosystems* are defined by the plants, animals, and microbes and their interactions in a given defined area. The systems are usually categorized as being *aquatic, terrestrial,* or *wetland.* Ecosystems depend on the local environmental quality, and also modify it. The production of methane (a product of organic decay), carbon dioxide (produced by oxidation), oxygen (a product of photosynthesis), and other atmospheric gases, along with particulate emissions such as pollen and spores, contribute to the local and downwind air quality. In addition, air contaminants from outside sources, both natural and anthropogenic, have their effects on ecosystems. Volcanic eruptions and other geologic processes produce sulfur compounds and other gases and particles that can significantly affect the health of ecosystems. In some cases, anthropogenic air pollutants from cities, farms, factories, and electric power plants impact local and distant ecosystems. Ecologists sample habitats and ecosystems for pollutants, assess the potential consequences, and propose remedial actions. Nearly 200 periodical scientific journals and, perhaps thousands of university programs, cover topics related to ecology and ecosystems.

Epidemiology and Controlled Studies

Many questions arise about the potential adverse effects of air pollution on human and animal health. What chemical and physical (e.g., mass, count, and surface area) characteristics of particles are the most important? What air concentrations of gases and particles are problematic? What are the biologic fates and health consequences of inhaled pollutants? How do effects of *acute* (brief, e.g., hours or a few days) and *chronic* (e.g., months, years, or decades) exposures to air pollutants differ? What segments of the population are particularly susceptible to developing adverse health effects? What are the biological mechanisms that occur within the body that can produce adverse health effects? There are many other important questions as well, but these examples serve to introduce epidemiology and toxicology in air pollution research.

The many roles of epidemiology in protecting public health are described in *Epidemiology for Public Health Practice* (Friis and Sellers, 2008) and *Environmental Epidemiology: Study Methods and Applications* (Baker and Nieuwenhuijsen, 2008). Epidemiology is primarily concerned with the scientific study of the distribution and causes of human diseases and deaths in populations. Epidemiology is essential for showing that a problem exists in the real world. Epidemiology can also establish *associations* between health data (such as deaths and hospital admissions) and environmental data (such as air concentrations of measured pollutants). If the associations are strong, such as those that imply a doubling or larger change (e.g., in normal death rates), there is a reasonable likelihood that the measured environmental parameters are *causes* of the adverse effects. Conversely, weak associations, such as a 1 percent increase in deaths, are more problematic when used as evidence that the measured environmental parameters are the actual causes. The measured pollutants might be *surrogates* for the real causes. For example, if the airborne particle mass is measured and the association is weak, the real culprit could be an unmeasured copollutant, or a combination of the measured particle mass and unmeasured factors. In addition, *confounders* (unexpected factors that produce the outcome of the study), such as lifestyle factors (e.g., smoking, diet, and obesity) and weather extremes, can act to obscure the epidemiology study conclusions. The main point is that epidemiology, although essential, usually cannot establish conclusive scientific causality without outside evidence. Yet strong epidemiologic findings alone can be convincing enough to stimulate regulatory action, as was done for cigarette smoking and the use of lead (Pb) in gasoline.

Sir Bradford Hill (1965) discussed the conditions by which a strong case for causality can be made by epidemiologists. Hill's conditions include the strength of the association, consistency, specificity, temporality, biological gradient, plausibility, coherence, and analogy (for an explanation of these criteria, see Chapter 10). Because epidemiology involves studies of real human populations exposed in real environmental conditions it is given great weight in air pollution research and regulatory decisions.

Controlled studies, such as *in vitro* (literally meaning "in glass"), include investigations of isolated biochemicals, living cells, laboratory animals, and human volunteers (also called clinical studies). These studies seek to control potentially confounding factors and to establish causality. In such well-controlled studies, suspected causal agents can be delivered in known concentrations without the significant interference of other factors (e.g., other exposures or stressors). Thus, causal factors, dose-response relationships, and mechanisms of action can be identified (see Chapter 9). As previously mentioned, it is the combination of well-conducted epidemiology studies and well-conducted controlled studies that are essential for protecting public health. Such controlled studies are performed by specialized scientists who are experts in using their specific experimental systems (e.g., cells, laboratory animals, and human subjects) and interpreting their findings. Because some segments of human populations are more susceptible to the adverse effects of air pollutants, a major challenge lies in developing animal models that respond similarly; such models are often referred to as *compromised animal models.*

About 150 periodical scientific journals cover the areas of epidemiology and toxicology. Many of these journals cover both areas, which allows their complementary nature to be appreciated. For each discipline to be successful, it must be aware of relevant advances in the other one.

Air Chemistry

The Earth's air is actually a complex and dynamic chemical mixture. Our air is a two-component system of particles suspended in a gas. When tiny particles are suspended in a gas, the mixture is called an *aerosol.* Although mostly made of the inert gas nitrogen (N_2), air is chemically active. To appreciate this reactivity, consider the second most abundant component, oxygen (O_2). This reactive gas is involved in both creating and destroying potentially problematic air contaminants. Diatomic oxygen (O_2) is split into two very reactive oxygen atoms (O) by ultraviolet light and by electrical discharges. Among other fates, these oxygen atoms can form ozone, which is triatomic oxygen (O_3). Ozone is chemically reactive, and in sufficient concentrations it can have adverse effects on living things. In the higher regions of the atmosphere (specifically the stratosphere) ozone interacts with ultraviolet (UV) radiation, which serves to reduce the UV levels at the Earth's surface, and thus diminishes the harm to living things. One way to think of this is that ozone is desirable at high altitudes, but undesirable at low altitudes (which is inhabited by living things). The chemistry of ozone is just one small example of the problems of interest to air chemists (see Chapters 3 and 5).

Air chemists do much more than just measure the substances and their reactions in the air. Developing new instrumentation and predictive computer models are important endeavors. Lightweight, inexpensive monitors that can be worn by human volunteers during normal activities are needed by epidemiologists who are trying to find the chemicals and concentrations in the air that pose potential risks. Fast-response biological aerosol monitors that can accurately identify harmful microbes immersed in the air with a variety of similar, but relatively benign ones, are also in need of further development. Collaboration among air chemists, microbiologists, and aerosol scientists is a key for success in improving field bioaerosol monitors. Another important issue, developing computer models that can predict the chemical behavior of the air, should not be overlooked. Without such models, air pollution episodes cannot be reliably predicted, let alone controlled. Attempts to control one air pollutant can even increase levels of other pollutants, and the unintended results could be significant. Also, the many effects of potentially expensive control measures cannot be predicted unless accurate air chemistry models are developed and validated. Air chemistry is a central scientific discipline in the study of air pollution, and it is continually improving the ability to understand and modify air quality.

Dosimetry

There is no question that the *initial doses,* which are defined as *the amounts initially deposited in the respiratory tract,* are critical determinants of the effects of air pollutants. Without a significant dose, there will be no significant toxic effect. *Dosimetry, i.e., the measurement of dose,* deals with several issues including the following examples:

- What descriptors of dose are appropriate?
- What are the doses to specific regions of the respiratory tract?
- What segments of the population receive the largest doses?
- How do age and gender (or probably more importantly, body size) modify doses?
- How does exercise modify dose?
- How do humans and laboratory animals differ with respect to doses?

The methods used by dosimetry researchers include:

- controlled laboratory studies involving human volunteers and laboratory animals;
- use of mathematical computer models to predict population and individual doses;
- use of markers (also called tracers) of inhaled doses; and
- development and validation of new computational dosimetry models, such as computational fluid dynamic (CFD) models and physiologically based pharmacokinetic (PBPK) models.

Scientists involved in dosimetry include mathematicians, physicists, engineers, physiologists, physicians, and veterinarians, to name a few. Chapter 7 includes more information on dosimetry.

Risk Assessment

Risk cannot be completely avoided, but it can usually be managed. If one were attempting to avoid all risk, one might resolve to not get out of bed each morning. But even then, lack of exercise and the absence of the beneficial pressure of life's many challenges would eventually lead to a deterioration of one's health. Nearly everything that people do is associated with risk. Since risk is inevitable, a method is needed for comparing various risks and prioritizing them so that money and effort spent on risk reduction can be properly apportioned. Money and talent are almost always short in supply and long in demand, so they must not be wasted.

In the early 1980s the U.S. Congress asked the National Research Council for help in providing advice on options for characterizing and managing risks. The result was a report, *Risk Assessment in the Federal Government: Managing the Process* (NRC, 1983). This report, also known as the "Red Book," set forth the elements of risk assessment. Risk assessment was described as having four phases:

- Hazard identification
- Dose-response assessment
- Exposure assessment
- Risk characterization

Risk assessment is intended to be followed by *risk management,* which involves using methods that will control risk. Risk assessment has become a mainstay in the methods used to analyze risks and to set priorities for their management. The topic was revisited by the National Research Council (NRC, 2009) by request of the U.S. EPA, for the purpose of improving the process (see Chapter 11). Risk assessment is in a period of modification, mainly to improve its efficiency with respect to its cost, time required, and responsiveness to specific needs.

Regulations

The pressure for industrial, domestic, and other uses of energy understandably leads to the widespread use of the many energy resources. As previously mentioned, the early use of wood and coal as fuels led to problems with air quality, including the associated adverse health effects. Today, the major fuels include coal, burner oil, natural gas, gasoline, diesel fuel, radioactive isotopes, and other, sometimes exotic, substances and technologies. Each of the currently-used fuels and technologies have their associated environmental contaminants. As time passes, the mix of energy sources changes. Advances in methods for energy production are presently being made rapidly. Thus, modern regulatory endeavors are more complex than those of the past.

Dr. Frederick Lipfert (1994) summarized some of the events that shaped the development of air pollution control. Focusing mainly on Great Britain, the United States, and Canada, Dr. Lipfert acknowledged that many other countries had similar histories. Effective regulatory activities probably began in the late 1800s. The Alkali Act in Britain in 1863 established official smoke inspectors. In 1881, the U.S. cities of Chicago and Cincinnati passed local smoke ordinances and California followed much later in 1947. The British Clean Air Act of 1956 (following the 1952 episode in London) regulated smoke, and the first U.S. Clean Air Act of 1963 called for cooperation of state and federal agencies in their enforcement efforts. Shortly afterward, the U.S. Air Quality Act of 1967 and the extended British Clean Air Act of 1968 more firmly set the stage for stern enforceable emission standards. In the United States a milestone event was the creation of the U.S. Environmental Protection Agency in 1970. These events were followed in 1971 by the Canadian Clean Air Act, and in 1980, the U.S. and Canada moved to develop policies to control transboundary air pollution. These and other events marked the basis of effective and evolving air quality regulation.

Several other U.S. agencies also moved to regulate air quality and to insure that funds and effort were dedicated to performing the necessary research efforts. The following organizations are active in their respective arenas: The Bureau of Mines; The Public Health Service; The National Institutes of Health; The National Institute for Occupational Safety and Health; The Occupational Safety and Health Administration; The Consumer Product Safety Commission; and the U.S. EPA. Thus, workers and the public have extensive efforts directed toward understanding their exposures and the health effects of air pollutants. Such efforts permitted defining acceptable levels of air pollutants to which humans are exposed. As previously mentioned, the variety of governmental agencies involved in air quality regulations is extensive. This complex topic is addressed in Chapter 6.

Environmental Justice

Although there are several ways to describe *environmental justice,* it can be defined as *the equal (or at least fair) treatment of those of all incomes, races, genders, cultures, and educational attainments with respect to the social and physical environments in which they work, live, and otherwise spend their time.* Disparities in exposure to violence, drug addiction, health care, and other social environmental factors are known to have strong influences on lifespan and disease rates (U.S. Department of Health and Human Services, 2002). Recently, there has been interest in examining disparities in environmental exposure to potential hazards in water, food, and air. Both outdoor and indoor air quality are generally known to be degraded in many communities that have low incomes and educational levels. Disentangling the combined impacts of income, education, other socioeconomic factors, and air quality on health is a formidable problem. Gee and Payne–Sturges (2004) argue that a major factor that increases the vulnerability to environmental hazards is psychosocial stress in disadvantaged communities. On the other hand, epidemiologists have reported that even when socioeconomic factors are accounted for, exposure to air pollution is associated with excess risks in certain disadvantaged populations (U.S. Department of Health and Human Services, 2002). Many challenges lie ahead in understanding the factors required to promote environmental justice.

VII. SUMMARY OF MAJOR POINTS

This chapter has traced the history of air pollution from before the emergence of humans to the present day. In addition to the pollutant sources and adverse effects, the emergence of awareness and current attitudes toward air contaminants has been described. The continuing tension between progress and the undesirable effects of air contaminants has stimulated large and diverse research efforts. In a sense, this introductory chapter has raised more questions than it has answered.

The story of air pollution and its effects on life predates human existence by billions of years. Natural forces have historically had the greatest impact on life forms, including mass extinctions and the destruction of vulnerable species. With respect to human activities, the conquest of fire and history of fuel usage over time led to observations of air pollution related diseases. Because of their often large exposures, the health and diseases of workers were the focus of several early writers. The introduction of coal as a partial replacement for wood as the fuel of choice changed the air pollution related disease burdens faced by both workers and the general public. Early thinkers and writers, including alchemists, helped to shape attitudes and develop the physical and intellectual tools that benefitted and brought together medical practice and chemistry. Concepts, such as the importance of dose, developed by Paracelsus hundreds of years ago, and John Evelyn's early ideas about vulnerable populations, are still important today.

The industrial revolution, and particularly the great air pollution disasters of the twentieth century, provided the impetus for both large research programs and meaningful regulatory actions related to the adverse effects of air pollution. Research efforts resulted in a realization that epidemiology and controlled studies of cell systems, laboratory animals, and human subjects were all necessary for identifying the important air pollutants and their harmful concentrations. Although it is clear that air pollutants must be regulated, it is also clear that many essential activities, including food production, manufacturing, transportation, electric power generation, and the practice of medicine unavoidably produce air contaminants. Thus, regulating these activities can have unintended effects on health, and these tradeoffs must be taken into account.

Several governmental agencies in the United States and worldwide have been created to study and regulate air quality in workplaces, outdoors, and in dwellings. Accordingly, current air regulations are complex and overlapping. A difficult challenge for the future relates to harmonizing worldwide environmental standards.

Today, the scope of air pollution research is very broad, including Earth sciences, climatology, meteorology, air chemistry, ecology, risk assessment, air quality regulations, and environmental justice. It is clear that we are still in an early phase of understanding and controlling the effects of air pollutants. In fact, it might be said that *air pollution science is in a state where chemistry was before the periodic table of the elements.* Thus, there are many challenges ahead, and therefore, many opportunities for careers in the field.

VIII. QUIZ AND PROBLEMS

Quiz Questions

(select the best answer)

1. The earliest life forms on the Earth:
    a. were much like the dominant plants and animals of today.
    b. were largely microorganisms that could survive in an atmosphere devoid of significant oxygen levels.
    c. did not require substantial concentrations of atmospheric oxygen to survive.
    d. Both b. and c are true.

2. The primary natural forces that have historically determined air quality include:
   a. volcanic eruptions.
   b. meteoric impacts.
   c. the industrial revolution.
   d. Both a. and b are true.
3. Primitive humans and ancient cultures did not experience poor air quality because they did not burn coal.
   a. True
   b. False
4. Modern attitudes toward anthropogenic air pollution were shaped by:
   a. thinkers and writers such as Galen, Pliny, and Paracelsus.
   b. Albert Einstein's theory of relativity.
   c. the great plagues, especially the "black death of the 14th and 15th centuries."
   d. None of the above are true.
5. The three great air pollution disasters were:
   a. caused by strong winds and low humidities.
   b. caused by strong winds and high humidities.
   c. not news at the time, but were recognized decades later.
   d. in the Meuse River Valley (1930), Donora, Pennsylvania (1948), and London (1952).
6. Epidemiologic investigations:
   a. provide the strongest evidence for establishing mechanisms of action of inhaled air pollutants.
   b. are relevant to establishing air pollution regulations because they study real human exposures.
   c. are not relevant to establishing air pollution regulations because of their shortcomings.
   d. use laboratory animals as their primary study subjects.
7. Diesel engines:
   a. emit water vapor and ozone, but not particles.
   b. should be banned because they do not provide essential services.
   c. are important contributors to public health due to their roles in farming, transportation, etc.
   d. Only a. and b. are true.
8. Earth science:
   a. deals with the oceans, the atmosphere, and the Earth's geology.
   b. uses observation satellites and aircraft to study the atmosphere.
   c. is represented in a large number of periodical scientific journals.
   d. All of the above are true.
9. Ozone:
   a. is also called "diatomic oxygen."
   b. is not very reactive chemically.
   c. is formed by the addition of oxygen to a zinc atom.
   d. is beneficial to living things when it is in the stratosphere.
10. Risk assessment:
   a. is a method that is used to eliminate all risks.
   b. is a formal process used to evaluate and prioritize risks by governmental agencies.
   c. is a follow-on process that follows risk management.
   d. was developed by Professor Firket in 1936.

Problems

1. Describe the risk assessment process and explain why it is important for establishing environmental regulations.
2. How did the ideas championed by Paracelsus contribute to our modern attitudes toward air pollution?
3. What were the major conclusions about the health effects of air pollutants that followed the great air pollution disasters?
4. Discuss the roles of governmental groups in understanding and controlling air pollutants.
5. In Table 1–4, which factors are most likely to:
   a. spread infectious diseases?
   b. produce an asthma attack in children?
   c. produce chemically-induced respiratory tract irritation?
6. What adverse health effects would occur if diesel engines were outlawed because of their emissions? List at least six adverse effects.
7. Strict air pollution regulations can both help and harm low socioeconomic status populations. Give an example of a harm.

IX. DISCUSSION TOPICS

1. Photosynthetic plant life utilizes carbon dioxide (CO_2) and produces atmospheric oxygen (O_2). Complex animal life consumes O_2 and produces CO_2. Over the next billion years do we expect the atmospheric O_2 concentration to increase, decrease, or remain about the same at 21 percent?

2. About 600 years ago Paracelsus claimed that all substances are poisons. Is this simple claim still true today? Are there exceptions?
3. In the great air pollution disasters of the twentieth century, deaths lagged the start of each air pollution episode by a few days. Why didn't the deaths show up sooner?
4. Would the immediate banning of all human activities that generate air pollution improve the human lifespan?
5. What are the most important career opportunities that relate to improving future air quality?

References and Recommended Reading

ACGIH®, 2009 TLVs® and BEIs®, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 2009.

Ashe, W. F., "Acute effects of air pollution in Donora, Pennsylvania," in *Air Pollution,* McCabe, L. C., ed., McGraw–Hill, New York, pp. 455, 458, 1952.

Baker, D. and Nieuwenhuijsen, M. J., eds., *Environmental Epidemiology: Study Methods and Applications,* Oxford University Press, New York, 2008.

Ball, P., *The Devil's Doctor: Paracelsus and the World of Renaissance Magic and Science,* Heinemann, London, 2006.

Brimblecombe, P., "Air pollution and health history," Chapter 2 in *Air Pollution and Health,* Holgate, S. T., Samet, J. M., Koren, H. S., and Maynard, R. L., eds., Academic Press, San Diego, CA, 1999, pp. 5–18.

Chen, Y., Craig, L., and Krewski, D., Air quality risk assessment and management, *J. Toxicol. Environ. Health, Part A—Current Issues,* 71:24–39, 2008.

Clayton, G. D. and Clayton, F. E., eds., *Vol 1, General Principles, Patty's Industrial Hygiene and Toxicology, 3rd Edition,* John Wiley, New York, 1978.

Dockery, D. W., Pope, C. A., Xu, X., Spengler, J. D., Ware, J. H., Fay, M. E., Ferris Jr., B. G., and Speizer, F. E., An association between air pollution and mortality in six U.S. cities, *N. Eng. J. Med.,* 329:1753–1759, 1993.

Dockery, D. W., Schwartz, J., and Spengler, J. D., Air pollution and daily mortality: Associations with particulates and acid aerosols, *Environ. Res.,* 59:362–373, 1992.

Evans, G. W. and Kantrowitz, E., Socioeconomic status and health: The potential role of environmental risk exposure, *Annu. Rev. Public Health,* 23:303–331, 2002.

Evelyn, J., *Fumifugium,* originally published by W. Godbid for Gabriel Bedel and Thomas Collins, London, 1661. Reprinted by Exter: The Rota, 1976. U.S. Library of Congress (www.http://lccn.loc.gov/78301303, accessed June 22, 2011).

Firket, J., Fog along the Meuse Valley, *Trans. Faraday Soc.,* 32:1192–1197, 1936.

Friis, R. H., and Sellers, T. A., *Epidemiology for Public Health Practice, 4th Edition,* Jones and Bartlett, Boston, MA, 2008.

Gallo, M. A., History and scope of toxicology, Chapter 1 in *Casarett & Doull's Toxicology: The Basic Science of Poisons, 7th Edition,* Klaassen, C. D. ed., McGraw–Hill, New York, 2008, pp. 4–5.

Garrison, F. H., *An Introduction to the History of Medicine, 4th Edition,* W.B. Saunders, Philadelphia, 1929, p. 136, 165, 205, 281, 344.

Gee, G. C., and Payne–Sturges, D. C., Environmental health disparities: A framework integrating psychosocial and environmental concepts, *Environ. Health Persp.,* 112:1645–1653, 2004.

Graham, J. D. and Wiener, J. B., eds., *Risk vs. Risk: Tradeoffs in Protecting Health and the Environment,* Harvard University Press, Cambridge, MA, 1995.

Hall, J. V., Winer, A. M., Kleinman, M. T., Lurmann, F. W., Brajer, V., and Colome, S. D., Valuing the health benefits of clean air, *Science,* 255, 14 February: 812–817, 1992.

Hill, A. B., The environment and disease: Association or causation?, *Proc. Roy. Soc. Med., Occup. Med.,* 58:295–300, 1965.

Holgate, S. T., Samet, J. M., Koren, H. S., and Maynard, R. L., eds., *Air Pollution and Health,* Academic Press, San Diego, 1999.

Kump, L. R., The rise of atmospheric oxygen, *Nature,* 451 (7176):277–278, 2008.

Lipfert, F. W., *Air Pollution and Community Health: A Critical Review and Data Sourcebook,* Van Nostrand Reinhold, New York, 1994, pp. 111–141.

Lippmann, M., Cohen, B. S., and Schlesinger, R. B., *Environmental Health Science: Recognition, Evaluation and Control of Chemical and Physical Health Hazards,* Oxford University Press, New York, 2003, pp. 3–12.

NRC (National Research Council), *Risk Assessment in the Federal Government: Managing the Process,* National Academies Press, Washington, D.C., 1983.

NRC (National Research Council), *Science and Decisions: Advancing Risk Assessment,* National Academies Press, Washington, D.C., 2009.

Olesen, B. W., International standards for the indoor environment, *Indoor Air,* 14:18–26, 2004.

Ottoboni, M. A., *The Dose Makes the Poison: A Plain Language Guide to Toxicology, 2nd Edition,* John Wiley and Sons, New York, 1997.

Phalen, R. F., *The Particulate Air Pollution Controversy: A Case Study and Lessons Learned,* Kluwer Academic Publishers, Boston, MA, 2002, pp. 15–27.

Pope, C. A. III, Review: Epidemiological basis for particulate air pollution health standards, *Aerosol Sci. Technol.,* 32:4–14, 2000.

Rall, D. P., Relevance of animal experiments to humans, *Environ. Health Perspect.* 32:297–300, 1979.

Shrenk, H. H., Heimann, H., Clayton, G. D., Gafafer, W. M., and Wexler, H., *Air Pollution in Donora, PA,* Public Health Bulletin No. 306, Public Health Service, Washington, DC, 1949.

Schwartz, J., Air pollution and daily mortality: A review and meta analysis, *Environ. Res.,* 64:36–52, 1994.

Taubes, G., Epidemiology faces its limits, *Science,* 269:164–169, 1995.

U.S. Consumer Product Safety Commission (http://www.cpsc.gov, accessed March 20, 2010).

U.S. Department of Health and Human Services, *Healthy People 2010: Understanding and Improving Health, 2nd Edition,* U.S. Government Printing Office, Washington, D.C., November, 2002 (http://www.health.gov/healthypeople, accessed April 21, 2009).

Wilkins, E. T., Air pollution and the London fog of December, 1952, *J. Roy. Sanitary Inst.,* 74:1–21, 1954.

Zanobetti, A. and Schwartz, J., Race, gender, and social status as modifiers of the effects of PM10 on mortality, *J. Occup. Environ. Med.,* 42:469–474, 2000.