United States
Environmental Protection
Agency

Air Pollution Training Institute (APTI)
Environmental Research Center, MD E142-01
Research Triangle Park, NC 27711

July 2003

Principles and Practices of Air Pollution Control

Student Manual

APTI Course 452
Third Edition

United States

Air Pollution Training Institute (APTI)

April 2003

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Principles and Practices of Air Pollution Control

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Second Edition

Authors
Dr. William Franek, PhD, PE
Mr. Lou DeRose, J.D.

Developed by
ICES Ltd.
EPA Contract No. 68D99022

Acknowledgments

The authors gratefully acknowledge the contribution of Alpha Gamma Technologies, Inc., whose preparation of SI:422 was used as the basis for this course development.

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This project has been funded wholly or in part by the United States Environmental Protection Agency under Contract No. 68D99022 to ICES, Ltd.

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Course Description

APTI 452: *Principles and Practices of Air Pollution Control* is a three-day, resident instructional course designed to present an introductory view of all major, practical aspects of air pollution control. The course is intended primarily for employees unfamiliar with governmental control of air pollution or those who require a general knowledge of the principles and practices associated with air pollution control. The lessons include information on control program history, health and environmental effects of pollution, air pollution meteorology, air quality management, ambient air quality monitoring, measurement and control of emissions, pollution prevention, laws and regulations, emission inventories, compliance and enforcement, and other related topics.

The course is taught at an instructional level equivalent to that of an advanced, undergraduate university course. The Air Pollution Training Institute curriculum recommends APTI 452: *Principles and Practices of Air Pollution Control* as an introductory course for all areas of study. The student should have minimally completed a college-level education and APTI Course SI:422 – *Air Pollution Control Orientation Course* (3rd ed.) or have a minimum of six months of applicable work experience.

How to Use This Manual

This manual is to be used during classroom instruction and telecourse sessions. The workbook contains instructional objectives and materials for each of the thirteen subject areas.

Each chapter provides a lesson goal, instructional objectives, subject narrative, and reference materials that may guide your study. Each chapter also contains a reproduction of selected lecture slides intended to guide your notetaking. The slides are presented to generally follow the course outline; however, the instructor may on occasion vary the order of presentation or present material not included in the workbook. Each student, therefore, should take thorough notes of the lecture content throughout the course, but not rely solely upon graphic reproductions for the course content.

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Control Program History

Lesson Goal

At the end of this lesson, you will demonstrate general understanding of and familiarity with the historical overview of air pollution control, program history, and the major legislative landmarks that have defined the parameters of air quality management in the United States by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Identify the historic episodes and events that led to passage of air pollution control legislation.

2. Discuss the five major influences that affected the development of air quality management programs in the United States.

3. Explain the hierarchy of government responsibilities and discuss the history of regulatory approaches by our local, state, and federal governments as it relates to air pollution management.

4. Describe federal regulatory involvement from the Air Pollution Control Act (1955) to the Clean Air Act Amendments (1990).

5. Explain the four regulatory strategies used in the development of an air pollution management program, and describe the implementation of our nation's air pollution management program.

6. Discuss the possible future developments of air pollution management.

Recommended Reading: Godish, Thad, "Regulation and Public Policy," *Air Quality*, 3rd Edition, Lewis: New York, 1997, pp. 237-286.

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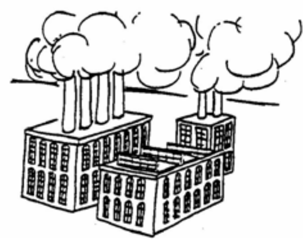
Control Program History

Air pollution has been a public health problem since the discovery of fire. In fact, incidents and episodes of air pollution have been documented throughout history. In ancient times, people used fire inside their caves and huts, often filling the air with harmful smoke. The Roman philosopher Seneca noted the “heavy air of Rome” in 61 A.D., and King Edward I strictly prohibited coal burning in London in 1273.

The origin of modern air pollution problems can be traced to eighteenth century England and the birth of the Industrial Revolution. As manufacturing replaced predominantly agricultural activities, populations shifted from the countryside to the city. What resulted was disastrous, as burgeoning populations strained rudimentary public utilities and services.

Energy that was desperately needed to heat public housing was often diverted for industrial purposes to fuel the ever-expanding Industrial Revolution. Great plumes of smoke and fly ash billowed from factories in the late eighteenth and nineteenth centuries, and air pollution problems escalated in the twentieth century with the advent of the automobile. The problem of air pollution grew in the mid-twentieth century, leaving catastrophic effects on human health and the environment in its wake.



Smoke, produced by burning coal and wood, was the earliest form of air pollution.

Smoke and ash produced by power plants contributed significantly to the problem of air pollution in the late 19th and early 20th centuries.

By 1940, air pollution in the United States and emerging public opinion pressured government regulators to act. Smog formed around Los Angeles, while other metropolitan areas around the country began to report degradations in air quality and visibility. Growing familiarity with environmental issues and increased public pressure hastened federal and state action.

California was the first state to pass air pollution regulations. Shortly after California acted in 1947, the federal government convened the first National Air Pollution Symposium composed of the leading environmental specialists and government representatives of the day. This landmark symposium marked the introduction of federal government involvement in environmental regulation.

In 1955, upheld by strong public support and improved science, Congress passed its first environmental legislation. From these meager beginnings the U.S. Environmental Protection Agency and an effective public policy toward the environment were instituted.

Air Pollution Control Programs

Five major influences that brought about the development of air pollution programs in the U.S. were air pollution episodes, improvements in science, environmental activism, changes in society and economy, and increased public awareness.

Air Pollution Episodes

Air pollution episodes result from the buildup of air pollutants and are often associated with a temperature inversion. Such episodes of high pollutant concentration have negative effects on public health and the environment. The six most notorious events occurred across three continents over a period of only 50 years. These represent the most deadly events associated with air pollution in the twentieth century. They provide direct evidence of the destructive capacity of modern air pollution.

By the 1940s, smog formed around Los Angeles and the first state environmental legislation was passed.

In 1955, Congress passed the first federal environmental legislation − the Air Pollution Control Act.

Muese River Valley (1930). The best known of the acute air pollution episodes occurred when pollutants were trapped in the Meuse River Valley of Belgium. Public officials observed a significant increase in reports of human death and illness when the concentration of air pollution was at its highest. Sixty-three people died in the first week of December 1930, prompting public health officials to examine the relationship between these deaths and high concentrations of SO_2 in the atmosphere. Their findings revealed that weather patterns had a significant impact on sulfur dioxide concentrations, particularly during periods of temperature inversion (Shy, 1978).

Donora, Pennsylvania (1948). In the early morning hours of October 26, 1948, a temperature inversion coupled with foggy weather settled over a horseshoe-shaped valley along the Monongahela River near Pittsburgh. Nestled in this valley was a small town of about 14,000 people—most were employed by the local steel mill, sulfuric acid plant, or zinc production facility. Twenty people died over a three-day period, largely due to cardiac and respiratory diseases. About half of the remaining population complained of cough, respiratory tract irritation, chest pain, headaches, nausea, and vomiting. Environmental experts agreed that the high concentrations of sulfur dioxide were largely responsible for these deaths and illnesses in Donora, Pennsylvania (Goldsmith and Friberg, 1977).

Poza Rica, Mexico (1950). Another catastrophic air pollution episode occurred in the small town of Poza Rica, Mexico when a natural gas plant released a toxic substance into the atmosphere. On the morning of November 24, 1950, the weather was foggy, winds were light, and an inversion layer had settled over the area. Shortly before sunrise, the plant began refining natural gas, releasing deadly hydrogen sulfide into the atmosphere. The poisonous gas was trapped near the ground, resulting in the deaths of 22 people and the hospitalization of another 320. The pattern was apparent: characteristic weather conditions, coupled with the toxic release of chemicals, were responsible for these deaths (Goldsmith and Friberg, 1977).

London Fog (1952). The episode that proved to be the most dramatic and costly to human health occurred in the London Fog of 1952. In a five-day period, a temperature inversion covered the Thames River Valley, trapping deadly acid aerosols in the atmosphere. More people died in this acute air pollution event than in any other

Sixty-three people died in the Muese River Valley due to exposure to high concentrations of SO_2.

Over 4,000 people died in 1950 when a deadly temperature inversion settled over London.

episode in recorded history. Over 4,000 people succumbed to bronchitis, pneumonia, and respiratory and cardiac disease. Because the death rate was so alarming, the British Parliament reinstated King Edward’s thirteenth century precedent and immediately barred the burning of soft coal in London (Shy, 1978).

Unfortunately, only ten years later a similar incident claimed an additional 700 lives. Historical records reveal the 1952 incident was not the only recorded event of its kind. Records also indicate there were detectable increases in deaths associated with fog in December 1873, January 1880, February 1882, December 1891, and again in December 1892. In total, 300 people died in the winter of 1948, while another 700 perished from particulate poisoning in 1963 (Goldsmith and Friberg, 1978).

New York City (1953). From November 15-24, 1953, approximately 200 people died of cardiac and respiratory ailments. Not surprisingly, records of a substantial increase in sulfur oxide concentrations coincided with a widespread atmospheric lull along the eastern seaboard of the United States at this time. Once again, substantial evidence warned public health officials of an impending crisis, yet accumulating weather data was not linked to health complaints until much later (Goldsmith and Friberg, 1978).

Bhopal, India (1984). Several decades passed before an event of these proportions occurred. On December 3, 1984, an incident took place that is noted as the world’s most deadly industrial accident. A Union Carbide pesticide plant accidentally leaked a highly toxic and poisonous gas into the slums of Bhopal, India. As

Bhopal's citizens slept, they were helpless in protecting themselves from the toxic gases that overcame them. Over 4,000 people died instantly of methyl isocyanate poisoning, while hundreds of thousands were permanently disabled, blinded, or injured. Today, the Indian government estimates an additional 15,000 deaths can be directly linked to the gas leak, while more than 500,000 people had unresolved claims pending before Indian courts late into the last century (Cohen, 1994).

Air pollution events such as these graphically demonstrate the fragile nature of human health and the environment and the disastrous effects that air pollution can have on both. Continued concern over events such as these has resulted in environmental legislation aimed at preventing such occurrences in the future.

Due to increased concentrations of sulfur dioxide and atmospheric inversions along the East Coast, over 200 people died in New York City.

Improvements in Science

As a result of air pollution episodes and public outcry about the Los Angeles smog problem, public policy initiated a search to find answers and causes. Researchers explored human health and the environmental effects of air pollutants. This research paved the way for improvements in science.

Air Pollution research began in California when the City and County of Los Angeles, and later the State of California, studied its smog problem. Around 1950, California Senator Thomas Kuchel appealed to the U.S. Congress stating that air pollution research efforts and costs should be borne nationally rather than exclusively by California. In 1955, President Eisenhower and Congress responded by passing legislation that provided for research on the health effects of air pollution.

In the early 1950s, Professor A.J. Haagen-Smith studied the Los Angeles smog problem and proved that, under ultraviolet irradiation, organic compounds and oxides of nitrogen react to produce smog. He demonstrated eye irritation, damage to green leaves, and light-scattering characteristics were byproducts of smog that were largely formed from emissions from autos reacting in sunlight.

Later, in 1963, P.J. Lawther used daily mortality and morbidity data to conclude that increased mortality results when sulfur dioxide levels exceed 0.71 mg/m^3 and suspended smoke exceeds 0.75 mg/m^3. Around 1965, the U.S undertook a major effort. to study the human health effects of specific pollutants. The purpose was to establish a causal relationship between diminished air quality and human disease and death. Pollutant studies included sulfur dioxide, particulate matter, oxidants, carbon monoxide, hydrocarbons, and nitrogen oxides.

Improvements were also made in science by the creation and growth of environmental health science and the increased quality of scientific research. By 1980, air pollution meteorology came of age and mathematical models of the pollution of the atmosphere were created. In addition, a wide variety of measuring instruments were developed to meet the pressing need for air quality monitoring systems.

Professor A.J. Haagen-Smith was one of the early pioneers to establish the link between smog and automobile emissions.

In 1963, P.J. Lawther advanced scientific understanding about the important link between human mortality and morbidity and pollutants in the atmosphere.

Over the last thirty years environmental science has become a discipline in itself, generating business and increasing the need to document and improve its knowledge base. This has led to a variety of scientific views, sometimes in support while at other times in opposition, but always directed toward refining the question of “What is good science?” and “How much do we have to know before we take action?”

Changes in Society and Economy

Population growth, industrialization, increased wealth and changing societal attitudes were among the significant changes that took place in our nation from about 1860 to 1960. These changes in society and the economy served as the third largest influence on air pollution programs.

In the late 1800s, some of the principal causes of death were infectious diseases such as influenza, tuberculosis, typhoid fever, malaria and venereal disease. As knowledge of and treatment for these diseases has improved, our average life span has increased from 40 to 75 years. As a result, many now survive long enough to die of long-term diseases such as arteriosclerosis, heart attacks, stroke, emphysema, and cancer. All of these long-term diseases can be related to environmental factors—including air pollution. With more people living longer and many dying of air pollution related diseases, our nation is increasingly concerned with the development of a cohesive air pollution control strategy.

The industrial revolution, which began in England in the 18th century, ultimately provided a higher standard of living through increased wages. This industrialization, while proving extremely beneficial for individual standards of living, had an immensely negative impact on the environment. Innumerable smokestacks decorated the landscape, spewing harmful toxins into breathable air. With the invention and proliferation of the automobile, our nation experienced a rapid growth in fuel consumption. Increases in such consumption caused the air pollution problem to proliferate from large cities to rural areas, creating unhealthy and unsightly smog.

Environmental concerns are a luxury only a wealthy nation can afford. While the poor were consumed with

Population growth, industrial-ization, increased wealth, and changing social attitudes were important factors that paved the way for increased concern about environmental issues.

attaining basic necessities, air pollution failed to gain importance. Those who participated in the environmental awaking were members of the ever-growing American middle class. Changing social attitudes were now more concerned with quality of life issues such as environmental protection.

Environmental Activism and Public Awareness

The final two influences on the development of air pollution control programs were an increased public awareness to environ-mental issues and the birth and development of environmental activism in this country.

Modern day concerns about the environment grew in the 1960's, with the surfacing of social revolution in the United States. Concern about the environment took its place alongside civil rights, consumer protection, safety and health, and a host of other issues that were on the public agenda at the time. The environmental movement that began in the 1960s was initially concerned with air and water pollution. Environmental activism was sparked by Rachel Carson's book *Silent Spring*, which revealed the problems of increased and unrestricted pesticide usage.

Carson connected the findings of toxicology, ecology, and epidemiology in a form easily understood by politicians and the general public. She discussed the bioaccumulation of fat-soluble insecticides in fatty tissues of fish and the birds that eat fish, the natural resistance of surviving insects to these toxins, the natural dispersion of the toxins far from the source of the substance. As a result of Carson's writing and other concerns expressed in society, people became more educated about the environment and its importance to human beings.

Environmental activism grew in the 1960's, and a worldwide Earth Day was organized in the spring of 1970—Earth Day has since become an annual observance dedicated to the awareness of environmental problems. Energized environmental activism brought about the establishment of several environmentally concerned public interest groups. Among these, the *Sierra Club* lobbies Congress on environmental issues ranging from nuclear energy to wetlands preservation, and the *Natural Resource Defense Council* blocks economic development in courts by suing firms for failure to pay adequate attention to environmental laws. Other environmental organizations include *The Friends of the Earth*, *The National Wildlife Federation*, *Environmental Action*, *Environmental Defense Fund*, and *The Nature Conservancy.*

Earth Day was first celebrated in the spring of 1970, and was one of the first precursors of environ-mental activism in the United States.

Today, private environmental organizations like these play an important role, not only in shaping public policy but advancing effective environmental education. Since 1971, the *National Association for Environmental Education* and other organizations like it have become an essential forum for teachers, conservationists, naturalists, and scientists to advance environmental viewpoints and perspectives.

Hierarchy of Government Responsibilities

The hierarchy of governmental air pollution responsibilities involves a top-down approach. The Federal Clean Air Act, while using federal oversight, mandates certain responsibilities to state governments, which in turn delegates certain responsibilities to local governments. Today, we have the hierarchy of government responsibilities, but historically air pollution was considered a local matter that was to be handled on a local level.

Local Governments

Before 1900, disputes about unwanted material in the air were resolved by common law nuisance (public or private) or trespass litigation. Thereafter, air pollution abatement under the nuisance doctrine gradually gave way to resolution by local governmental ordinances. In 1881, Chicago and Cincinnati were the first to pass air pollution laws. These ordinances regulated smoke emissions from furnaces and locomotives. By 1920, 175 municipalities had air pollution ordinances, and by 1940 this number grew to over 200.

These ordinances defined smoke as dense, black, or gray opacity. Problems with this definition led to the adoption of the Ringelman Chart for percent opacity. Originally most communities prohibited smoke darker than No. 3 on the Ringelman scale (60% opacity). Since then, there has been a progressive decrease in allowable smoke density. Today, the majority of opacity ordinances prohibit opacity greater than 20%.

Air pollution complaints were originally litigated through common law nuisance or trespass provisions before 1900.

State Governments

At the turn of the century, courts of law expanded state authority by finding air pollution control actions were within Tenth Amendment, “police power” of the state, statutes. In 1910 and 1912 respectively, Massachusetts and Rhode Island were the first states to pass air pollution (smoke control) laws. In 1947, California was the first state to pass laws regulating air pollution beyond regulating black smoke emission from industrial stacks. This law gave authority to counties to regulate air pollution. Oregon, in 1952, passed the first state law that provided statewide authority to a state air pollution control agency. In 1956, California formed its first state air pollution control agency and to address air pollution problems from automobiles. In 1959, California passed legislation that provided for ambient air quality standards to be established. These standards, in which cost would not be a factor, were to be related to health effects, including irritation to humans, and damage to vegetation and visibility. These standards were the harbinger for our nation’s air pollution program.

Later, in the 1980s, states took the lead on air pollution issues. As news spread of the 1984 accident in Bhopal, India, public awareness grew regarding the exposure and effects of hazardous pollutants. Local concerns about specific facilities, potential accidents, and long-term exposure to potential carcinogens surfaced. Because the federal air toxics program was tied up in litigation, states responded by developing their own air toxics regulations.

Federal Government

Air Pollution Control Act (1955). As a result of the public’s growing concern about air pollution and the states’ agitation over dealing with what they thought was a national problem, the federal government entered the picture for the first time with the passage of the Air Pollution Control Act of 1955. This Act required the U.S Department of Health, Education and Welfare (HEW) to research the effects of air pollution and pollution control. This Act also gave federal funding for research, training and technical assistance to the states with the hope that states would set up their own air pollution programs. The Act considers control of air pollution at its source to be primarily the responsibility of state and local governments. Congress extended the

Air Pollution Control Act (1955) initiated federal funding for air pollution research and provided training and technical assistance to the states.

Enforcement of air pollution laws grew out of an expanded 10th Amendment authority granted to governmental agencies by the courts.

Air Pollution Control Act in 1959 and again in 1962 without any expanded role of the federal government.

Clean Air Act (1963). During the Kennedy administration, Congress debated the federal verses the states' roles in dealing with the air pollution problem. President Kennedy supported greater federal responsibilities. The compromise was the Clean Air Act of 1963 (replacing the 1955 Act), which funded states to establish their own air programs, and required HEW to develop air quality criteria for advisory purposes only. The 1963 Act encouraged state, regional, and local programs for the control and abatement of air pollution, while reserving federal authority to intervene in interstate conflicts only.

Motor Vehicle Air Pollution Control Act (1965). Debates between Senator Edmund Muskie (D-ME) and the automotive industry resulted in the passage of the Motor Vehicle Air Pollution Control Act of 1965, which was an amendment of the 1963 Clean Air Act. This Act gave the federal government authority to set automobile emission standards only for carbon monoxide and hydrocarbon emissions. However, before the government could set any emission limitations, the manufactures voluntarily complied with installing pollution controls on their 1968 vehicles.

Air Quality Act (1967). By early 1967, the debate in Congress continued about the degree of federal involvement. Should there be ambient air quality standards or emission standards for stationary sources? Should these standards be national standards or regional standards? The result was the enactment of the Air Quality Act of 1967, which required HEW to designate "air quality control regions" within the United States and issue air-quality criteria documents and control technology information. States were responsible for establishing regional air quality standards based on federal air quality criteria, and comprehensive plans for implementing these air quality standards according to a fixed-statutory timetable. In the following two years, the federal program was not implemented according to the required time schedule. Setting up air quality control regions were too complex and HEW was understaffed. Where air quality control regions were established, states either failed to designate air quality standards or were slow in establishing implementation plans. Consequently, President Nixon and Congress proposed new legislation in 1970.

Air Quality Control Act (1967) established Air Quality Control Regions (AQCRs) designed to issue air quality criteria and control techniques for states.

The Clean Air Act Amendments (1970). By 1970, air and water pollution was a top ranking public concern and thus became a very important political issue. Therefore, Congress in 1970 amended the Clean Air Act (CAA), which sharply increased federal authority over regulation of air pollution. This Act increased authority to the newly created, Environmental Protection Agency (EPA) and established the basic structure of our nations' present air quality management program. (The EPA was created by President Nixon's "Reorganization Plan No. 3," about one month prior to the promulgation of the 1970 CAA Amendments.) The 1970 CAA Amendments established federal, uniform, National Ambient Air Quality Standards (NAAQS) and required the states to produce an implementation plan that would make their state's air quality meet these NAAQS. The Amendments placed the major responsibility for control of air pollution from stationary sources on the states via their implementation plans.

Also, the 1970 Amendments designated exclusively the control of air pollution from new mobile sources to the EPA; however, California was allowed to maintain its existing mobile source program. Thus EPA began to set the standards for new automobile engines, fuels or fuel additives, and aircraft emissions. The reason for this was obvious: if every state had a different standard for mobile source emissions, there could be a substantial interference with interstate commerce. Therefore, the 1970 CAA Amendments enacted the National Emission Standards for Hazardous Air Pollutants (NESHAPs), in order to identify and regulate "hazardous air pollutants." The Amendments also empowered EPA to establish New Source Performance Standards (NSPS) for significant sources of air pollution. The lawmakers addressed governmental oversight and accountability by allowing citizens to sue the EPA for non-performance of a non-discretionary act and to sue a company for air pollution violators.

The principal result of implementation of the 1970 CAA Amendments was to establish a basic air quality management system and organization in this country. Unfortunately, these progressive measures did not have the effect Congress anticipated; the problem of diminished air quality did not improve a great deal at that time.

Clean Air Act Amendments (1970) established a uniform NAAQS and provided federal enforcement authority in air pollution emergencies.

Clean Air Act Amendments (1977). The 1970 CAA Amendments had lofty aspirations; it required that all air quality regions attain compliance with NAAQS by 1975. Although significant progress was made, many control regions did not achieve compliance with one or more NAAQS. Meanwhile, in 1972 there was litigation on whether states had a non-discretionary duty to prevent significant deterioration of clean air in areas that already met the NAAQS.

Recognizing the importance of these two issues, Congress significantly amended the Clean Air Act in 1977. The 1977 CAA Amendments added the "Prevention of Significant Deterioration" (PSD) and "Nonattainment" Provisions to the Act. These provisions established the New Source Review program for construction and modification of new major sources. For those areas that did not meet NAAQS, the 1977 CAA Amendments provided a much longer and realistic time frame for states to achieve compliance with the NAAQS. Other initiatives that the 1977 CAA Amendments addressed were the strengthening of the auto emission standards and the regulation of chemicals that destroyed the stratospheric ozone layer.

Clean Air Act Amendments (1990). By 1990 the air quality in several urban regions of the United States had only marginally improved. As of 1990, 96 U.S. cities were nonattainment for ozone, 41 cities for carbon monoxide and 70 cities for particulate matter less than 10 microns (PM10). From 1970 to 1990, only seven NESHAPS had been established for hazardous air pollutants. Besides air toxics, public interest grew on a wide range of issues such as acid rain and stratospheric ozone protection.

In order to address these and other concerns, Congress passed what has become the most lengthy and complex piece of environmental legislation ever enacted: the Clean Air Act Amendments of 1990. In approximately 145,000 new words, Congress essentially tripled the length of the prior Act. The 1990 Amendments completely overhauled the hazardous air pollution program, strengthened the enforcement and nonattainment provisions, and added the operating permit, acid rain and ozone depletion programs.

The 1990 CAA Amendments designated new classifications of nonattainment for ozone, carbon monoxide and PM10 depending on the severity on nonattainment. The more severe the classification, the more time the region was allowed to comply and the more stringent was the state's implementation plan.

Clean Air Act Amendments (1990) created a tough, new industrial permitting program, overhauled the hazardous air pollution program, and expanded federal authority over non-compliance of NAAQS.

Clean Air Act Amendments (1977) added the Prevention of Significant Deterioration Pro-gram (PSD) and the nonattainment provisions.

Since the EPA had a difficult time designating substances as hazardous air pollutants, the 1990 Amendments listed 189 substances as hazardous air pollutants and required the EPA to establish technology-based control standards.

In order to reduce acid rain, the 1990 Amendments also created a program that would limit the amount of sulfur dioxide and nitrogen oxides emissions from large electric utility power plants. The Amendments protected stratospheric ozone by regulating the production of ozone-destroying chemicals such as chlorofluorocarbons. The Amendments initiated the Title V Permit Program, which required major sources to secure a detailed operating permit that would be valid for only five years. In addition, the amendments also greatly expanded federal enforcement provisions; criminal penalties were expanded to include felony provisions and EPA administrative powers were significantly increased via “administrative penalty orders.”

Air Pollution Management

Strategies

The ability to control air pollution in a coordinated manner is known as Air Pollution Management. Air Pollution Management is a collection of strategies and tactics used to reduce air pollution and protect the public health and welfare. These strategies, however, can vary greatly in both purpose and function. For example, achieving pollution reduction goals by imposing an emissions tax is philosophically quite different from using emissions standards in order to achieve pre-determined ambient air quality standards. Regardless of the approach, an effective air pollution management program is simply a collection of air pollution strategies designed to provide a solution to difficult municipal, state, and federal air quality problems.

While different strategies may be used to manage air quality, they each strive to meet a common goal of cleaner air.

Cost-benefit analysis, air quality standards, emissions standards, and economic incentives are all modern air pollution manage-ment strategies.

Air pollution management strategies can take many forms. These include cost-benefit analysis, air quality standards, emission standards, and economic incentives. In the United States, air pollution management is implemented by using mainly a combination of the air quality standard and the emission standard strategies. However, in other parts of the world, techniques used in the United States are often replaced by the use of emission standards, emission taxation, and cost-benefit analysis.

Emission Standard Strategy. An emissions standards strategy establishes, for an individual emitter or group of emitters, an approved range of emissions that conforms to local, regional, or national goals for their area (De Nevers, et al., 1977). Emission levels are often formed without reference to national air quality goals, instead focusing on pollution levels as they relate to the source, topography, and meteorological trends of the surrounding area. This strategy is used throughout many European countries. In the U.S., two sections of the CAA are pure emission standard approaches. These are the New Source Performance Standards, NSPS program, and the hazardous air pollution program, which uses “Maximum Achievable Control Technology, MACT, and National Emission Standards for Hazardous Air Pollution, NESHAP.

Economic Incentive Strategy. Another method of controlling industrial pollutant emissions is through the use of an economic incentive strategy. Emission taxation is considered one of the larger members of the economic incentive strategy class. An emissions tax strategy taxes an emitter based on a published scale relating to the rate of emission (De Nevers, et al., 1978). In theory, the tax rate would be established in such a manner that most major polluters would find it more economical to install pollution control devices than pay the additional emissions tax. Many versions of emission taxes have been proposed in the U.S., but none have become law.

Other members of the economic incentive strategy have become part of the CAA. For example, a market-oriented economic strategy has been used as part of the acid rain program of the 1990 CAA Amendments. It provides for market trading of sulfur dioxide emission allowances. A company has the right to apply unused allowances to offset emissions at other plants, trade allowances to other sources, or to purchase allowances in lieu of installing air pollution control equipment.

The economic incentive strategy relies on an emissions tax to motivate polluters to install effective air pollution control devices.

Emissions Standards establish an approved range of emissions for a point or area source. This strategy is used in many European countries.

Cost-benefit Strategy. Another way to control air pollution is through use of a cost-benefit analysis that attempts to assess the damage of various pollutants in order to estimate the cost of controlling them. The goal of a cost-benefit strategy is to select the pollution control alternative which best minimizes the effect of air pollution damage in the most cost-effective manner. This strategy assumes that we must accept some amount of air pollution damage. It also suggests that we attempt to decide rationally, how much damage is acceptable and, correspondingly, how much should we spend to reduce damages to appropriate levels (De Nevers, et al., 1978).

Conducting a cost-benefit strategy is very difficult. There are frequently too many uncertain factors and variables to be analyzed. For this reason it would be very difficult to base air pollution regulations on a direct application of this theory. However, greatly simplified approaches are authorized under the CAA. For example, the EPA must take costs into account when establishing a New Source Performance Standards, Reasonable Available Control Standards and Maximum Achievable Control Technology Standards. When EPA takes costs into account, they are doing a simplified cost-benefit analysis.

Air Quality Standard Strategy. The air quality standard strategy is the most dominant strategy used by our nation. This strategy establishes ambient air quality standards from dose-response and other toxicology data. It sets a pollutant exposure value, below threshold values, so that there can be no resulting air pollution damage. Once an ambient air quality standard is established, regulatory authorities are responsible for creating and implementing a plan that will ensure that the air quality standard is not exceeded. The following table by Noel De Nevers, from *Air Pollution Control Engineering*, illustrates the advantages and disadvantages of the different control strategies (De Nevers, et al., 1978).

The air quality standard strategy relies on a set of enforceable air quality standards. This strategy is most commonly used in the United States.

The cost-benefit strategy selects the most effective control technology or method to achieve pollution control in the most cost-effective manner.

Table 1-1. Comparison of Air Quality Management Strategies

Strategies	Cost	Simplicity	Enforceability	Flexibility	Adaptability
Air Quality Management	Good	Poor	Fair	Fair	Fair
Emission Standards	Terrible	Excellent	Excellent	Poor	Fair
Emission Taxes	Fair	Excellent	Excellent	Unnecessary	Good

Cost-benefit Analysis	Excellent	Terrible	Unknown	Unknown	Good

(Source: A.C. Stern, *Air Pollution* Vol. V (Academic Press: New York, 1977), p. 33.

Implementation

Implementation of our nation's primary air pollution management strategy (air quality standards) incorporates several elements. These are, identification of National Ambient Air Quality Standards (NAAQS), measurement ambient air quality, development of an accurate inventory of source emissions, establishment of an effective enforcement procedure, and creation of a predictive methodology and models to evaluate air quality. Ultimately, the success or failure of an air quality standard system is directly related to the thorough and deliberate application of each element.

The CAA requires the EPA to set NAAQS "with an adequate margin of safety…to protect human health." These are called health-based standards. At present, we have NAAQS for six criteria pollutants: ozone, sulfur dioxide, carbon dioxide, nitrogen dioxide, lead and particulate matter less than 10 microns.

The CAA requires states, in their State Implementation Plan (SIP), to establish and maintain a comprehensive air-monitoring network, which defines the status of ambient air quality in their state. The ability to effectively store, retrieve, and analyze pollutant emission information is critical to ensure that estimates are correct, accurate, and properly interpreted

A precise inventory of all source emissions within a region (whether from man-made or natural sources) must be cataloged. Ideally, a thorough emissions inventory would include a source designation, location (recorded in grid

State Implementation Plans (SIPs) establish a comprehensive air-monitoring network to ensure NAAQS compliance.

NAAQS establishes measurable limits for six criteria pollutants: ozone, sulfur dioxide, carbon dioxide, nitrogen dioxide, lead, and particulate matter.

coordinates and stack height), and an emission schedule (emission rate and plume-rise parameters expressed as an hour and day of the year). Air quality management can only be as accurate as the baseline information provided to it through the emission inventories of a particular region.

Next, a methodology must be created that relates air quality to emissions. Because so many factors can affect the transport and dispersion of pollutants, an ideal model is one that accurately predicts the air quality for any location at any time and under any set of meteorological conditions. Normally, this might include some type of air diffusion model that includes local meteorological patterns; unfortunately, most models of this type lack the level of sophistication and predictability required for accurate analysis. Air pollution modeling can only tell air quality policy managers what amount of reduction in emissions is necessary to meet ambient air quality standards; however, modeling cannot ensure compliance.

Air quality policy managers must have at their disposal the necessary equipment and methods for achieving NAAQS objectives. Control technology or methodology must be technically and economically feasible and enforceable in order to assure compliance. Although air pollution control technology and research have matured sufficiently to provide a variety of control solutions for specific emissions, newly identified pollutants and standards will require the development of additional strategies and tactics.

The final element of effective air quality management is enforcement. Goals and standards, effective methods and monitoring strategies, and comprehensive emissions inventories are little more than objectives without binding enforcement. Establishing regulations, conducting public hearings, and publishing compliance schedules are all part of the enforcement effort, and required by a state's SIP. The SIP should be dynamic enough to permit revision when progress is demonstrated or more rigid enforcement when non-compliance occurs.

Air pollution modeling tells air quality policy managers what amount of reduction in emissions is necessary to meet ambient air quality standards.

Successful enforcement proced-ures require quantitative regulatory requirements, public hearings, published compliance schedules, and well-constructed SIPs.

Future Focus of Responsibility

Most of the air pollution abatement efforts taken to date are no more then a temporary solution. Today's abatement efforts do not address the roots of the problem of air pollution—topics such as inappropriate energy, transportation, and industrial systems. These efforts are concerned with pollution abatement devices like baghouse filters, electrostatic precipitators, scrubbers and afterburners. These technologies provide necessary immediate reductions to air pollution, but are not the ultimate solution. They create other environmental problems, such as water and solid-waste pollution, and do little, if anything, to reduce carbon dioxide emissions that contribute to global warming. They are best viewed only as a bridge to when renewable sources, such as solar, wind, and waterpower, or some newly discovered source would provide the bulk of the world's energy.

It is essential that governments put economic incentives for energy reform into place as part of their air quality strategies. Power plants must become more efficient and use cleaner fuels.

Urban society must change their transportation systems, by shifting away from automobiles to a more pollution-friendly form of transportation or workable mass transit system. Getting people to carpool, to ride buses or bicycles to work, or to walk to work are all feasible alternatives. Efforts to control air pollutants should focus on waste minimization prevention rather than emission control devices. Our focus should be on pollution prevention rather than pollution control. An example of this kind of process change was the replacement of most uses of asbestos with other suitable, non-toxic forms of insulation. Another example would be switching to compressed natural gas, propane, or ethanol from leaded gasoline in motor vehicles.

Indoor air pollution is an environmental issue that is growing in public concern. The CAA addresses only outdoor air pollution, while mainly OSHA and building codes regulate indoor air quality. Most people spend the majority of their daily hours indoors. Numerous studies have shown that indoor air is contaminated by a wide variety of pollutants, with some being in higher concentrations than outdoor air. As a result, people are often more exposed to high concentrations of pollutants indoors than out. Therefore, in the coming years more studies and regulations of indoor air will most likely be initiated and promulgated.

Renewable resources such as wind, solar, and water power may one day provide the majority of the world's energy needs.

Recently, public attention has been focused on two less traditional but potentially more serious environmental difficulties: the breakdown of the protective layer of stratospheric ozone, and the accumulation of carbon dioxide and other so-called greenhouse gases that could significantly increase global temperatures and change climate patterns. These two concerns require additional research and investment in the coming years, so we can both understand and control the harmful effects associated with these dangers.

Today, politicians attempt to resolve air pollution issues by balancing what is “ideal” against what is “practical.” But this balance between eliminating air pollution emissions and respect for the increasing costs and workability of achieving such a goal is delicate. Responsibility for such decisions requires continued public interest and awareness about vital issues such as indoor air pollution, global warming, ozone depletion, alternative transportation, and new sources of energy generation.

The breakdown of stratospheric ozone and the accumulation of greenhouse gases are two of the most serious environmental issues facing policy makers today.

NAME ________________________________ DATE _______________
SCORE _________

CHAPTER 1 CONTROL PROGRAM HISTORY

Multiple Choice

Directions: Read each question and choose the best answer. Write the letter of your answer in the space provided.

1. Which of the following catastrophic air pollution events was **not** an air pollution episode that resulted from a severe temperature inversion?

a. Belgium (Meuse River Valley)
b. London, England
c. Bhopal, India

d. Poza Rica, Mexico
e. Donora, Pennsylvania **1.** ________

2. Each of the following factors has directly influenced the policy objectives of air pollution control programs, **except** __________.

a. air pollution episodes
b. changes in society and the economy
c. improvements in science
d. atmospheric dispersion of pollutants
e. environmental activism **2.** ________

3. The state of Oregon is significant to the air pollution control program history because in 1952 it __________.

a. pioneered studies in human health and the environmental effects of smog
b. promulgated the first state emission standards for HAPs
c. established the first state air pollution control agency
d. led the United States in the growth of state air toxics programs
e. advanced the first citizen lawsuit against an industrial polluter **3.** ________

4. The U.S. Environmental Protection Agency was formed in __________.

a. 1955
b. 1963
c. 1967
d. 1970
e. 1977 **4.** ________

5. Which of the following was **not** a significant achievement of the Clean Air Act Amendment of 1990?

a. Completely overhauled the hazardous air pollution program.
b. Added an extensive operating permit program for major sources.
c. Significantly strengthened enforcement provisions of the CAA.
d. Placed regulations on ozone-destroying chemicals.

e. Discouraged market-based incentives for meeting NAAQS. **5.** ________

6. Who was the first historic figure to regulate the use of coal burning?

a. King James I (1228)
b. King Edward I (1273)
c. King Richard III (1377)
d. King Henry V (1413)

e. King James II (1442) **6.** ________

7. Which of the following substances is a federally regulated criteria pollutant?

a. Asbestos
b. Lead
c. Radon
d. Mercury

e. Benzene **7.** ________

8. The basic structure of our nation’s present air quality management program was established by which of the following acts?

a. Air Pollution Control Act (1955)
b. Clean Air Act (1963)
c. Air Quality Act (1967)
d. Clean Air Act Amendment (1970)

e. Clean Air Act Amendment (1977) **8.** ________

Matching

Directions: Match the description that best defines each event and record the letter in the space provided.

A. Air Pollution Episodes

________ **9.**	(1930) Meuse River Valley	**a.**	Twenty people died and almost 7,000 became sick due to a four-day fog of SO_2 that surrounded a small mill town.

________ **10.**	(1948) Donora, Pennsylvania	**b.** Two hundred people died due to pneumonia, influenza, and cardiac arrest. Excess deaths continued several weeks after the episode caused by an epidemic of influenza.
________ **11.**	(1952) London, England	**c.** Sixty-three people died due to high concentrations of SO_2 in the atmosphere during a severe temperature inversion.
________ **12.**	(1953) New York City	**d.** A Union Carbide plant accidentally released methyl isocyanate gas into the atmosphere that killed 2,800 people and injured over 200,000.
________ **13.**	(1984) Bhopal, India	**e.** The most acute air pollution episode in recorded history in which over 4,000 people died of bronchitis.

B. Legislative Landmarks

________ **14.**	(1955) Air Pollution Control Act	**f.** Established the Air Quality Control Regions (AQCRs) designed to issue air-quality criteria and control techniques for states.
________ **15.**	(1963) Clean Air Act	**g.** Added the Prevention of Significant Deterioration Program (PSD) and the nonattainment provisions**.**
________ **16.**	(1967) Air Quality Act	**h.** Initiated federal funding for air pollution research and provided technical assistance to the states; lawmakers restricted federal authority to preserve state and local autonomy.

________ **17.**	(1970) CAA Amendments	**i.** Created a tough, new industrial permitting program, overhauled the hazardous air pollution program, and expanded federal authority over noncompliance of NAAQS.
________ **18.**	(1977) CAA Amendment	**j.** Initiated the first federal oversight of state air pollution action and established grants for states to expand air pollution control programs.
________ **19.**	(1990) CAA Amendments	**k.** Established a uniform NAAQS and pro-vided federal enforcement authority in air pollution emergencies and interstate clean air violations.

Historical Time Line

Directions: Record the events that took place in the space provided.

Control Program History

1930 1940 1950 1960 1970 1980 1990

(1930)

(1940)

(1947)

(1949)

(1950)

(1952)

(1953)

(1955)

(1963)

(1967)

(1970)

(1977)

(1980)

(1984)

(1990)

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	C	1-4
2.	D	1-4
3.	C	1-11
4.	D	1-12
5.	E	1-14
6.	B	1-3
7.	B	1-17
8.	D	1-12
9.	C	1-5 1-6
10.	A	
	E	

11.

B

12.

D

13.

H 1-11 1-14

14.

J

15.

F

16.

K

17.

G

18.

I

19.

1930	Muese River Valley
1940	California Smog Study
1947	First State Air Pollution Law (CA)
1949	First Federal Air Pollution Symposium
1950	Poza Rica, Mexico
1952	First Air Pollution Control Agency (Oregon) & London, England
1953	New York City
1955	Air Pollution Control Act
1963	Clean Air Act
1967	Air Quality Act
1970	USAPA established, CAA Amendment
1977	CAA Amendments
1980	State Air Toxics Programs established
1984	Bhopol, India
1990	CAA Amendments

CHAPTER 2

Human Health and the Environmental Effects of Air Pollution

Lesson Goal

Demonstrate an understanding of the criteria used to measure the hazardous effects of air pollutants and how they affect the human body and environment by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Describe the human respiratory system and how air pollution affects it.
2. List six criteria pollutants and the human health or environmental effects of their exposure.
3. Recognize general types of damage to vegetation and property that can be caused by air pollutants.
4. Discuss causes and effects of the greenhouse effect, stratospheric ozone depletion, acid rain and visibility impairment.
5. List the four components of a risk assessment and how they operate.

Recommended Reading: Godish, Thad, "Health Effects" and "Welfare Effects" *Air Quality*, 3rd Edition, New York: Lewis, 1997, pp. 137-178, and 179-214.

"*Latest Findings on National Air Quality: 1999 Status and Trends,"* EPA – 454/F-00-002 (August 2000).

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Human Health and Environmental Effects of Air Pollution

Air pollution remains one of the major human health problems of our day and affects every community in the United States. Epidemiological studies document the relationship between air pollution and human health effects. Although many diseases and illnesses can be traced back to air pollution, reduction in lung function is one of the most debilitating effects of long-term exposure and even has been found to significantly diminish life expectancy (Evans and Wolff, 1991).

Epidemiological studies indicate that air pollution reduces lung function and significantly diminishes life expectancy.

The quality of the air we breathe directly affects our own survival and nature's ability to flourish. In reviewing the effects of air pollution, this chapter will discuss the damage done to human health and environmental systems.

Hazardous Effects of Air Pollutants on Human Body Systems

Air pollution has a direct effect on human health. Throughout history, we have learned that acute air pollution episodes result in tremendous loss of life due to cardiac and respiratory disease, bronchitis, and pneumonia. In the most dramatic of these episodes, air pollution combined with specific meteorological conditions and topographical features of the region to produce a deadly concentration of atmospheric pollutants. As previously discussed, the best known of these episodes were those that occurred in the Muese River Valley region of Belgium (1930), Donora, Pennsylvania (1948), London, England (1952, 1962), New

Acute air pollution episodes can result in chronic human health problems such as cardiac and respiratory disease, bronchitis, and pneumonia.

York City (1953), and Bhopal, Indian (1984). These air pollution episodes were responsible for the deaths of thousands of people.

A receptor is any organ or environmental system that can be affected by air pollution.

Pollutant Movement Through The Body. Human receptors include the skin, eyes, nose, or respiratory system, while environmental receptors may include animals, vegetation, or natural resources. A receptor such as the human skin is an organ like any other found in the body. It serves as a protective barrier to shield the body from outside pollutants and is extremely resilient against most forms of environmental damage. However, by contrast, the eye is also a receptor but is significantly more susceptible to damage and irritation than the skin. While many compounds might scar or disfigure the skin, it retains its functional purpose, while the same compounds introduced into the eye would render it completely useless.

Air pollutants get into the body mainly through breathing. They can also be ingested or absorbed through the skin. For example, children who eat or play in contaminated soil can acquire chronic, life-long health problems. Once a pollutant enters the body it can remain in the lungs (like asbestos), be exhaled, or move into the blood from the lungs (like the oxygen we breathe) or from the digestive system or skin. If pollutants enter the bloodstream, they can be transported to all parts of the body. As it moves through and around the body, a pollutant can undergo many chemical changes, especially as it passes through the liver, becoming less, or more, toxic. The pollutant can be exhaled, it can leave the body in urine, bowel movements, sweat, or breast milk, or it can be stored in hair, bone, or fat.

Hazardous air pollutants can result in many health problems simply by interfering with normal body functions. The most common way they interfere is by altering the chemical reactions that take place within individual cells, the building blocks of all living things. These changes can kill cells, impair cell function, or redirect cell activity. The results can be very damaging to organs, result in birth defects when the cells of an unborn child are damaged, or cause cancer to grow within cells at an uncontrolled rate.

The elderly, infants, pregnant women, and those who suffer from long-term chronic lung or heart disease are the most vulnerable to the effects of air pollution.

Although the human health effects of air pollution can vary greatly from one person to another, those most directly affected by ambient air pollution include the elderly, infants, pregnant women, and those who suffer from long-term chronic lung or heart disease. In addition, those who engage in vigorous physical activity outdoors are also vulnerable due to the amount of air exchange that takes place in deep lung tissue.

Human exposure to air pollution usually manifests itself as either an acute (short-term) or chronic (long-term) health effect. An acute health effect is usually immediate and reversible when exposure to the pollutant ends. Common acute health effects include eye irritation, headaches, and nausea. A chronic health effect frequently results in lasting, irreversible effects and occurs only after extended periods of exposure. Some of the indicators of chronic health effects include decreased lung capacity, heart disease, cancer, and even death.

Acute air pollution episodes rarely account for the chronic public health problems associated with long-term exposure to air pollution. Generally, chronic health problems are the product of sustained exposure. Although pollutants routinely affect many human body systems, the respiratory system is perhaps the most vulnerable because it is the mechanism of transport and filtration. As the body's principle pathway for air pollution, the respiratory system has the most direct and immediate contact with raw pollutants.

Acute health effects result in immediate, but temporary damage. Chronic health effects produce lasting health problems.

Upper Respiratory System. Typically, pollutants enter the body as air is inhaled through the nose or mouth into the upper respiratory system. Prior to reaching the lower respiratory system, most of the larger particulate matter (>15µm diameter) is removed from the body by small nasal hairs or by the mucus membranes that line the respiratory tract from the nasal cavity through the nose and throat (Talukder and Sharma, 1991).

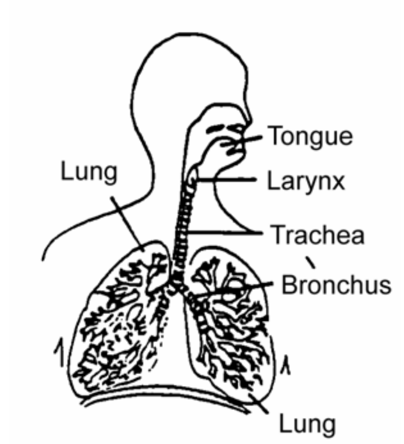


Fig. 2-1. Upper Respiratory System

Particulate matter >15 µm is removed by nasal hairs and mucus membranes. Pollutants <10 µm are trapped by the cilia that line the respiratory system.

Smaller pollutant particles (<10µm diameter) that escape these defense mechanisms become trapped in the cilia. The cilia are fine, hair like structures that line the respiratory system walls through the bronchioles. Their wave-like motion carries mucus and trapped particulate matter toward the upper respiratory tract for expulsion. As demonstrated, the body has several defense mechanisms to combat and expel particulate matter.

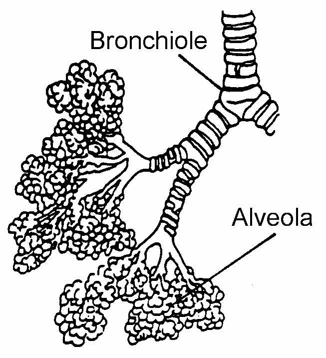
The cilia are the body's last line of defense in the bronchioles before reaching the alveoli. Particles measuring between ~1μm to ~0.1μm in diameter that escape capture by higher defense mechanisms eventually settle in the alveoli where it may take weeks, months, or even years to expel the particles. Alveolar tissue fights the foreign matter by producing phagocyte cells that will eventually envelop it, permanently holding the particulate in place. However, once the particulate matter is surrounded, the soluble toxins are then removed and transported through the bloodstream to other parts of the body. Although this method of trapping particulate matter in the alveolus is one of the body's natural defense mechanisms, it is still dangerous for PM to reach such depths in lung tissue.

Gaseous air pollutants affect lung function by slowing the action of the tiny cilia in the respiratory tract.

Gaseous air pollutants affect lung function in many ways, but most notably by slowing the action of the tiny cilia. The continual act of breathing polluted air can dramatically slow the body's ability to perform this normal, but essential, cleansing function. A breakdown of this kind of normal body function frequently results in pollutant particles escaping capture by the cilia and becoming deeply embedded in lung tissue. The potential, chronic (long-term) health effects of particulate matter are lung cancer, pulmonary emphysema, bronchitis, asthma, and other respiratory infections. (Godish, 1997).

Due to the delicate nature of the bodily structures, both particulate and gaseous pollutants can have a profound effect on the upper respiratory system. From here the upper respiratory system becomes a conduit for the transport of pollutants to the lower respiratory system.

Lower Respiratory System. The lower respiratory system is composed of the bronchi, bronchioles, and alveoli and forms the area we refer to as the location in the lungs where most pollutant exchange occurs. As air passes from the upper respiratory system, past the trachea, it passes into either the left or right bronchi. Each bronchus further subdivides into smaller tubes called the bronchioles. The bronchioles end in millions of tiny air sacs called alveoli. Despite the natural cleansing process, much of man-made pollution never escapes the lower respiratory system.



The direct respiratory effects of lung damage often result in bronchitis, pulmonary emphysema, lung cancer, pneumoconiosis, cough, and chest pain. Although less noticeable, the indirect effects of lung damage are of equal importance. Indirect damage can result in decreased respiratory efficiency, diminished pulmonary circulation, enlargement and weakening of the heart and blood vessels, skin and eye irritation, inflammation, and allergic reaction.

The hazardous effects of air pollution on both the upper and lower respiratory systems are significant because they impede the lung's ability to absorb oxygen from the air and remove harmful carbon dioxide from the bloodstream. Permanent damage done to the lungs often results in the reoccurrence of respiratory disease and the increased incidence of heart and circulatory problems.

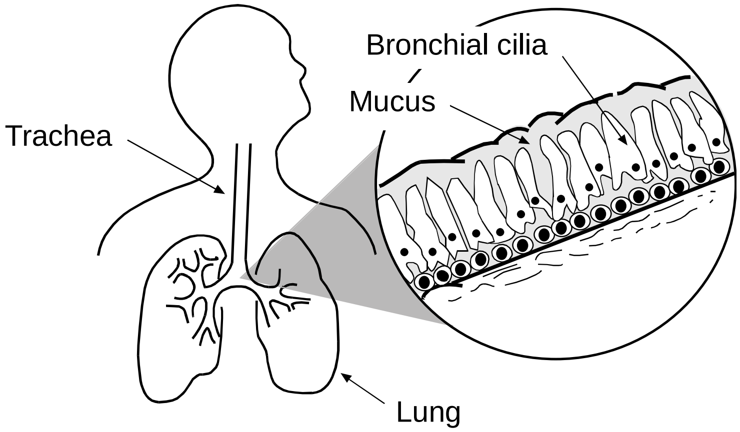


Figure 2-3. Bronchial Tubes

The respiratory system is well equipped with many structural mechanisms to remove and clear particulate matter from the airways; however, they are helpless to protect against the long-term exposure of toxins and pollutants often found in urban-industrial areas. Depending on the aerodynamic size of the inhaled particles and the velocity of the respiratory air movement, criteria pollutants can quickly overcome the body's natural defense mechanisms. Once pollutants are absorbed into the bloodstream as a chemical or gas, the harmful toxins can be transported to a distant organ or tissue to create a variety of adverse effects.

Criteria Pollutants

Particulate Matter (PM)

Health Effects. Particulate matter is the general term used for a mixture of solid particles and liquid droplets found in the air. Some particles are large or dark enough to be seen as soot or smoke. Others are so small they can hardly be detected with an electron microscope. $PM_{2.5}$ describes the "fine" particles that are less than or equal to 2.5 micrometers in diameter. "Coarse" particles refers to particles greater than 2.5, but less than or equal to 10 micrometers in diameter. PM_{10} refers to all particles less than or equal to 10 micrometers in diameter. Just to put this in perspective, ten micrometers are about one-seventh the diameter of human hair.

Particulate matter includes both fine and coarse particles. When inhaled, these particles can accumulate in the respiratory system and are closely associated with numerous health effects. Exposure to coarse particles is primarily associated with aggravation of respiratory conditions, such as asthma. Fine particles are also closely associated with such effects as premature mortality of elderly persons, increased hospital admissions and

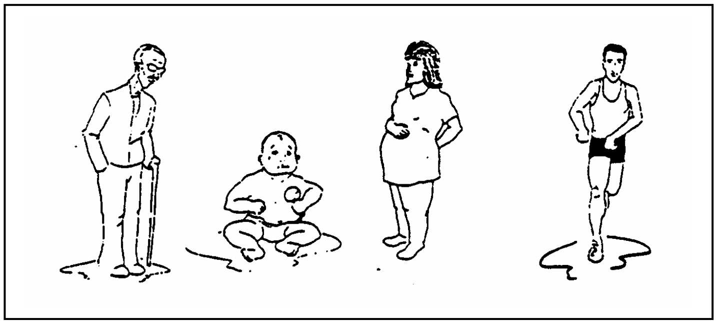


Figure 2-4. Susceptible Populations

emergency room visits for heart and lung patients, increased respiratory symptoms and disease among the chronically ill, and decreased lung function in almost all population groups. However, those groups that appear to be at greatest risk to such effects include the elderly, individuals with cardiopulmonary disease such as asthma, and children.

Sources of the Pollutant. Particulate matter originates from many different stationary and mobile sources as well as from natural sources. Fine particles result from the fuel combustion of motor vehicles, power generation, and industrial facilities, as well as from residential fireplaces and wood stoves. Sources of coarse particles include vehicles traveling on unpaved roads, materials handling, crushing and grinding operations, and windblown dust. Some particles are emitted directly from their sources, such as smokestacks and cars. In other cases, gases such as SO_2, NOx, and VOCs interact with other compounds in the air to form fine particles. Their chemical and physical compositions vary depending on location, time of year, and weather.

Trends in PM Levels. Between 1990 and 1999, average PM10 concentrations decreased 18 percent, while PM10 emissions decreased 16 percent. EPA is not yet able to characterize the long-term trends for PM2.5 in urban areas, but this research continues. In early 1999, EPA initiated a new monitoring network to begin assessing the nature of the PM2.5 problem. By December 2000, the network consisted of approximately 1,700 monitors at over 1,100 sites. EPA is now analyzing these data for future reports.

PM emission trends are improving. Between 1990 and 1999, PM concentrations decreased 18%, while emissions decreased 16%.

Lead (Pb)

Lead concentrates and accumulates in bones and soft tissue. A high concentration of lead poisons the blood, nervous and renal systems.

Health Effects. Lead (Pb) forms stable compounds, which persist and accumulate both in the environment and in the human body. Lead enters the human body through ingestion and inhalation with consequent absorption into the blood stream and distribution to all body tissues. Clinical, epidemiological and toxicological studies have demonstrated that exposure to lead adversely affects human health.

Low-level lead exposure has been found to interfere with specific enzyme systems and blood production. Kidney and neurological cell damage has also been associated with lead exposure. Animal studies have demonstrated that lead can contribute to reduced fertility and birth defects. Children are the most sensitive to many of lead's adverse effects. Recent studies show that lead also may be an important factor in high blood pressure and subsequent heart disease.

Other serious potential effects from lead exposure are behavioral. Brain damage has been well documented in cases of severe lead poisoning in children. Restlessness, headaches, tremors and general symptoms of mental retardation have been noted. The brain seems to be particularly sensitive to lead poisoning, yet it is unclear whether low-level exposure will result in brain dysfunction. Although evidence exists which indicates that children with above-normal blood lead levels are more likely to demonstrate poor academic performance, the studies remain inconclusive.

Ambient concentrations of lead have decreased 94% since 1980, while lead emissions decreased 95% over the same 20-year period.

Trends in Lead Levels. Historically atmospheric lead came primarily from the combustion of leaded gasoline. However, the use of unleaded gas since 1975 has reduced mobile source lead emissions by over 90%. Currently stationary sources, such as lead smelters, battery manufacturers, iron and steel producers and others are the focus of regulatory action. The 1999 average air concentration of lead is 94 percent lower than in 1980. Emissions of lead decreased 95 percent over the same 20-year period. Today the only violations of lead NAAQS occur near large industrial sources such as lead smelters.

Sulfur Dioxide (SO_2)

Health Effects. The effects of SO_2 on health are irritation and inflammation of tissue that it directly contacts. Inhalation of SO_2 causes bronchial constriction resulting in an increased resistance to air flow, reduction of air volume and a marked increase in the respiratory and heart rate.

High concentrations of SO_2 can result in temporary breathing impairment for asthmatic children and adults who are active outdoors. Short-term exposures of asthmatic individuals to elevated SO_2 levels during moderate exertion may result in breathing difficulties that can be accompanied by such symptoms as wheezing, chest tightness, or shortness of breath. Other effects that often have been associated with longer-term exposures to high concentrations of SO_2, in conjunction with high levels of PM, include respiratory illness, alterations in the lungs' defenses, and aggravation of existing cardiovascular disease. The population groups most susceptible to these conditions include individuals with cardiovascular or chronic lung disease, as well as children and the elderly.

SO_2 can exacerbate pre-existing respiratory diseases (asthma, bronchitis, emphysema). The enhancement (synergism) by particulate matter of the toxic response to sulfur dioxide has been observed under conditions, which would promote the conversion of sulfur dioxide to sulfuric acid. The degree of enhancement is related to the concentration of particulate matter. A two-fold to three-fold increase of the irritant response to sulfur dioxide is observed in the presence of particulate matter capable of oxidizing sulfur dioxide to sulfuric acid.

Sulfur dioxide poisoning inhibits the respiratory system and increases airway resistance adding to heart-lung load.

Sulfuric acid (H_2S0_4) inhalation causes an increase in the respiratory system's mucous secretions, which reduces the system's ability to remove particulates via mucociliary clearance. This can result in an increase incidence of respiratory infection.

Sources of SO_2. Sulfur dioxide is an atmospheric pollutant that results from combustion processes (mainly burning of fossil fuels containing sulfur compounds), petroleum refining, sulfuric acid manufacturing and smelting of ores containing sulfur. Fuel combustion, largely from coal-fired power plants, accounts for most of the total SO_2

emissions. The reduction of sulfur dioxide pollution levels can generally be achieved by using low sulfur content fuels or chemical sulfur removal systems.

Once the atmosphere becomes contaminated with sulfur dioxide, it can be oxidized (either photochemically or in the presence of a catalyst) to SO_3 (sulfur trioxide). In the presence of water vapor, SO_3 is readily converted to sulfuric acid mist. Other basic oxides combine with SO_3 to form sulfate aerosols. Sulfuric acid droplets and other sulfates are thought to account for about *5* to 20 percent of the total suspended particulate matter in urban air. These compounds can be transported large distances and come back to earth as a major constituent of acid rain. Many of the resultant health problems attributed to SO_2 are the result of SO_2 oxidation to other compounds.

Ambient concentrations of sulfur dioxide have decreased 50% since 1980, while emissions have dropped 28%.

Trends in SO_2 Levels. Nationally, average SO_2 ambient concentrations have decreased 50 percent from 1980 to 1999 and 36 percent over the more recent 10-year period 1990–1999. SO_2 emissions decreased 28 percent from 1980 to 1999 and 21 percent from 1990 to 1999. Reductions in SO_2 concentrations and emissions since 1994 are due, in large part, to controls implemented under EPA's Acid Rain Program beginning in 1995.

Carbon Monoxide (CO)

Carbon monoxide interferes with the blood's ability to provide an adequate supply of oxygen to body tissue.

Health Effects. The toxic effects of high concentrations of CO on the body are well known. Carbon monoxide is absorbed by the lungs and reacts with hemoglobin (the oxygen carrying molecule in the blood) to form carboxyhemoglobin (COHb). This reaction reduces the oxygen carrying capacity of blood because the affinity of hemoglobin for CO is over 200 times that for oxygen. The higher the percentage of hemoglobin bound up in the form of carboxyhemoglobin, the more serious is the health effect.

The level of COHb in the blood is directly related to the CO concentration of the inhaled air. For any given ambient air CO concentration, the COHb level in the blood will reach an equilibrium concentration after a sufficient time period. This COHb equilibrium level will be maintained in the blood as long as CO ambient air level remains unchanged. However, the COHb level will slowly change in the same direction as the CO concentration as a new equilibrium of CO in the blood is established.

The lowest CO concentrations shown to produce adverse health effects often result in aggravation of cardiovascular disease. Studies indicate that these concentrations have resulted in decreased exercise time before the onset of pain in the chest and extremities of individuals with heart or circulatory disease. Slightly higher CO levels have been associated with decreases in vigilance, the ability to discriminate time intervals and exercise performance. Evidence also exists of a possible relationship between CO and heart attacks, as well as the development of cardiovascular disease and impaired fetal development.

Sources of the Pollutant. Carbon monoxide (CO) is a colorless, odorless and, at high levels, a poisonous gas, formed when carbon in fuel is not burned completely. It is a component of motor vehicle exhaust, which contributes about 60 percent of all CO emissions nationwide. Non-road vehicles account for the remaining CO emissions from the transportation sources category. High concentrations of CO generally occur in areas with heavy traffic congestion. In cities, as much as 95 percent of all CO emissions may come from automobile exhaust. Other sources of CO emissions include industrial processes, non-transportation fuel combustion, and natural sources such as wildfires. Peak CO concentrations typically occur during the colder months of the year when CO automobile emissions are greater and nighttime inversion conditions (where air pollutants are trapped near the ground beneath a layer of warm air) are more frequent.

Trends in CO Levels. Nationally, the 1999 ambient average CO concentration was 57 percent lower than that for 1980, and is the lowest level recorded during the past 20 years. CO emissions levels decreased 22 percent over the same period. Between 1990 and 1999, ambient CO concentrations decreased 36 percent, while the estimated number of exceedances of the national standard decreased 93 percent. During the same period, CO emissions fell 7 percent. This improvement occurred despite a 30 percent increase in vehicle miles traveled in the United States during the period.

Ambient concentrations of carbon monoxide have decreased 57% since 1980, while emissions have dropped 22%.

Nitrogen Dioxide (NO_2)

Health Effects. Nitrogen dioxide (NO_2) is a reddish brown, highly reactive gas that is formed in the ambient air through the oxidation of nitric oxide (NO). Nitrogen oxides (NOx), the term used to describe the sum of NO, NO_2 and other oxides of nitrogen, play a major role in the formation of ozone, particulate matter, and acid rain.

Short-term exposures (i.e., less than 3 hours) to low levels of nitrogen dioxide (NO_2) may lead to changes in airway responsiveness and lung function in individuals with pre-existing respiratory difficulties and increases in respiratory illness in children (5–12 years old). Long-term exposures to NO_2 may lead to increased susceptibility to respiratory infection and may cause permanent alterations in the lung. Nitrogen oxides react in the air to form ground-level ozone and fine particle pollution, which is associated with adverse health effects.

Sources of the Pollutant. The major sources of man-made NOx emissions are high-temperature combustion processes, such as those occurring in automobiles and ower plants. Home heaters and gas stoves also produce substantial amounts of NO_2 in indoor settings.

Although ambient concentrations of nitrogen dioxide have decreased 25% since 1980, emissions have increased 1%.

Trends in NO_2 Levels. Over the past 20 years, monitored levels of NO_2 have decreased 25 percent. All areas of the country that once violated the national air quality standard for NO_2 now meet that standard. While levels around urban monitors have fallen, national emissions of nitrogen oxides (which include NO, NO_2 and other oxides of nitrogen) have actually increased over the 20 years by one percent. This increase is the result of a number of factors, the largest being an increase in NOx emissions from off-highway diesel vehicles. This increase is of concern because NOx emissions contribute to the formation of ground-level ozone (smog), and other environmental problems like acid rain and nitrogen loading to water bodies.

Ozone (O_3)

Formation of Ozone. Photochemical oxidants result from a complex series of atmospheric reactions initiated by sunlight. When reactive (non-methane) hydrocarbons and

NOx accumulate in the atmosphere and are exposed to the ultraviolet component of sunlight, the formation of new compounds, including ozone and peroxyacetylnitrate, takes place.

Absorption of ultraviolet light energy by NO_2 results in its dissociation into nitric oxide and an oxygen atom. The oxygen atoms, for the most part, react with atmospheric molecular oxygen (O_2) to form ozone (O_3). In general, nitric oxide will react with O_3 to re-form NO_2, completing the cycle. A build-up of O_3 above the equilibrium concentration defined by the reaction cycle given above results when nitrogen oxide reacts with non-methane hydrocarbons. Oxygen atoms from the hydrocarbon radical oxidize nitric oxide to NO_2 without ozone being used up. Thus O_3 concentrations are not depleted and can build up quickly.

Ozone can also be formed naturally in the atmosphere by electrical discharge, and in the stratosphere by solar radiation. The former process is not capable of producing significant urban concentrations of this pollutant; however, there is some belief that the incursion of ozone from the stratosphere can contribute significantly to elevated ground level concentrations of O_3 under certain meteorological conditions.

Health Effects. Short-term (1–3 hours) and prolonged (6–8 hours) exposures to ambient O_3 have been linked to a number of health effects of concern. For example, increased hospital admissions and emergency room visits for respiratory causes have been associated with ambient O_3 exposures. Exposures to O_3 can make people more susceptible to respiratory infection, result in lung inflammation, and aggravate pre-existing respiratory diseases such as asthma. Other health effects attributed to O_3 exposures include significant decreases in lung function and increased respiratory symptoms, such as chest pain and cough.

These effects generally occur while individuals are engaged in exertion. Children, active outdoors during summer months when ozone levels are at their highest, are most at risk of experiencing such effects. Other at-risk groups include adults who are active outdoors (i.e., outdoor workers) and individuals with pre-existing respiratory disease, such as asthma and chronic lung disease. In addition, longer-term exposures to moderate levels of ozone present the possibility of irreversible changes in the lung structure, which could lead to premature aging of the lungs and worsen chronic respiratory illnesses.

Environmental Effects. Ozone also affects vegetation and ecosystems, leading to reductions in agricultural and commercial forest yield, reduced growth and survivability of tree seedlings, and increased plant susceptibility to disease, pests, and other environmental stresses (i.e., harsh weather). In long-lived species, these effects may become evident only after several years or even decades, thus having the potential for long-term effects on forest ecosystems. Ground-level ozone damage to the foliage of trees and other plants also can decrease the aesthetic value of ornamental species as well as the natural beauty of our national parks and recreation areas.

Sources of the Pollutant. Ozone is not emitted directly into the air but is formed by the reaction of VOCs and NOx in the presence of heat and sunlight. Ground-level ozone forms readily in the atmosphere, usually during hot summer weather. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources.

Nitrogen oxides are emitted from motor vehicles, power plants, and other sources of combustion. Changing weather patterns contribute yearly to many differences in ozone concentrations from region to region. Ozone and the precursor pollutants that cause ozone also can be transported into an area from pollution sources found hundreds of miles upwind.

Trends in Ozone Levels. Over the past 20 years, ambient ozone levels decreased 20 percent based on 1-hour data, and 12 percent based on 8-hour data. Between 1980 and 1999, emissions of VOCs have decreased 33 percent. During that same time period, emissions of NOx increased 1 percent. Because sunlight and heat play a major role in ozone formation, changing weather patterns contribute to yearly differences in ozone concentrations.

Ambient ozone levels decreased 20% since 1980, while VOC emissions have dropped 33%.

To better reflect the changes that emissions have on measured air quality concentrations, EPA is able to make analytical adjustments to account for this annual variability in meteorology. For 53 metropolitan areas, the adjusted trend for 1-hour ozone levels shows steady improvement from

1980 through the mid-1990s. The adjusted ozone levels decreased an average of 1 percent per year through 1994. However, beginning in 1994, the improvement appears to slow.

For the period 1980 to 1999, the downward trend in 1-hour ozone levels seen nationally is reflected in every broad geographic area in the country. The Northeast and West exhibit the most substantial improvement while the South has experienced the least rapid progress in lowering ozone concentrations. Table 2-1 lists the health effects associated with each criteria pollutant.

Table 2-1. Human Health Effects of Criteria Pollutants

CRITERIA POLLUTANT	BODY SYSTEM	HEALTH EFFECTS
Particulate Matter ($PM_{2.5}$ and PM_{10})	**Lower respiratory system.** Particulate matter less than 10 μm in diameter gets into the lower respiratory system, particularly during exercise.	• Asthma • Bronchitis • Reduced lung function • Cancer • Heavy metal poisoning
Lead (Pb)	**Organs and soft tissue.** Lead concentrations and accumulates in bones and soft tissue. A high concentration of lead in the body poisons the blood, nervous and renal systems.	• Anemia • High blood pressure • Cancer • Neurological disorders • Intellectual function
Carbon Monoxide (CO)	**Circulatory system.** Carbon monoxide interferes with the blood's ability to provide an adequate supply of oxygen to body tissue.	• CO poisoning • Angina pectoris • Neurological dysfunction • Brain damage • Fetal abnormalities • Asphyxiation
Nitrogen Dioxide (NO_2)	**Respiratory system.** NO_2 is very toxic at high levels.	• NO_2 poisoning • Asthma • Lowered resistance to infection
Sulfur Dioxide (SO_2)	**Respiratory system.** SO_2 poisoning directly affects the respiratory system and increases airway resistance adding to heart-lung load.	• Asthma • Bronchial constriction • SO2 poisoning • Heart attack
Ozone (O_3)	**Respiratory system.** Tropospheric ozone results in irritation of the respiratory system.	• Lung inflammation • Reduced lung elasticity • Transient cough • Chest pain • Throat irritation • Nausea

Toxic Air Pollutants

Nature and Sources. Toxic or hazardous air pollutants are those pollutants that cause or may cause cancer or other serious health effects, such as reproductive disorders, birth defects, or adverse environmental and ecological effects. Examples of toxic air pollutants include benzene, found in gasoline; perchloroethylene, emitted from some dry cleaning facilities; and methylene chloride, used as a solvent by a number of industries. Most air toxics originate from man-made sources, including mobile sources (i.e., cars, trucks, and construction equipment) and stationary sources (i.e., factories, refineries, power plants), as well as indoor sources (i.e., building materials and activities such as cleaning). Some air toxics are also released from natural sources such as volcanic eruptions and forest fires.

Health and Environmental Effects. People exposed to toxic air pollutants at sufficient concentrations may experience various health effects including damage to the immune system, as well as neurological, reproductive (i.e., reduced fertility), developmental, respiratory and other health problems. Many of these toxins may increase the risk of developing cancer or experiencing other serious health effects. In addition to exposure from breathing air toxics, risks also are associated with the deposition of toxic pollutants onto soils or surface waters, where they are taken up by plants and ingested by animals and eventually magnified up through the food chain. Like humans, animals may experience health problems due to air toxics exposure.

Trends in Toxic Air Pollutants. EPA and states do not maintain a nationwide monitoring network for air toxics, as they do for many of the other pollutants discussed. EPA has developed a National Toxics Inventory (NTI) to estimate and track national emissions trends for the 188 air toxics regulated under the Clean Air Act. In the NTI, EPA divides emissions into four types of sectors: (1) major (large industrial) sources; (2) area and other sources, which include smaller industrial sources, like small drycleaners and gasoline stations, as well as natural sources, like wildfires; (3) on-road mobile, including highway vehicles; and (4) non-road mobile sources, like aircraft, locomotives, and construction equipment.

Based on 1996 estimates, the most recent year of available data, the sources of toxic air pollutants are equally divided between the four types of sources. However, this distribution varies from city to city.

While EPA and the states collect monitoring data for a number of toxic air pollutants, the chemicals monitored, and the geographic coverage of the monitors varies from state to state. Together with the emissions data from the NTI, the available monitoring data help track trends in toxic air pollutants in various locations around the country. EPA is in the process of expanding the national monitoring network for a number of toxic air pollutants.

Air toxics have decreased 23% since 1990.

Based on the data in the NTI, estimates of nationwide air toxics emissions have dropped approximately 23 percent between 1990 and 1996. Although changes in how EPA compiled the national inventory over time may account for some differences, EPA and state regulations, as well as voluntary reductions by industry, have played an important role in achieving large reductions in overall air toxic emissions.

Environmental Effects of Air Pollution

Ecosystem. Long before pollutant effects become manifest in human health, they were seen in the environment. When sulfur dioxide (SO_2) and nitrogen oxides (NOx) are transformed into acids in the atmosphere, the resulting precipitation (rain, snow, or fog) is deposited onto vegetation and into the lakes and soil.

Damage to vegetation usually occurs in the structural mechanisms of the leaf since it is the leaf that provides the mechanics for growth. A leaf is typically divided into three parts: (1) the epidermis (outer protective layer), (2) the mesophyll (the spongy center section), and (3) the veins (a dense network of tubes that carries nutrients throughout the plant). When plants are exposed to SO_2, O_3, NO_2, and acid rain, all three structures are inextricably damaged (Wark and Warner, 1976).

Property Damage. Property damage is another significant by-product of air pollution. Research has shown that acid rain can destroy irreplaceable cultural treasures such as buildings and outdoor art. In addition, acid rain cracks and splits rubber products, nylon, polymer plastics, paint dyes, and other textiles. Acidification not only soils buildings, clothing, and automobiles, but also deteriorates the metal and stone in our buildings and monuments.

Pennsylvania discovered that 26% of its native trout streams could not support viable populations of brook trout due to acidic conditions.

Quality of Life. Quality of life is another matter that is also diminished by particulate matter and ozone formation. Pristine vistas can be significantly altered by air pollution transported from several hundred miles away. For example, pollutants can substantially affect outdoor sports and recreation. One survey of sixty-one native trout streams in southwestern Pennsylvania found that 26% of the streams studied did not support viable populations of brook trout due to acidic conditions (Swistoock, et al., 1991). Likewise the cosmetic appearance of our homes and cars require significant expenditures of time and money to remain free of the damaging effects of air pollution.

Acid Rain

Electric utility plants that burn fossil fuels produce approximately 64% of annual SO2 emissions and 26% of NOx emissions.

Nature and Source of the Problem. Acidic deposition or “acid rain” occurs when emissions of sulfur dioxide (SO_2) and nitrogen oxides (NOx) in the atmosphere react with water, oxygen, and oxidants to form acidic compounds. These compounds fall to the Earth in either dry form (gas and particles) or wet form (rain, snow, and fog). Some are carried by the wind, sometimes hundreds of miles, across state and national borders. In the United States, electric utility plants that burn fossil fuels produce about 64 percent of annual SO_2 emissions and 26 percent of NOx emissions.

Health and Environmental Effects. Before falling to the Earth, SO_2 and NOx gases and related particulate matter (sulfates and nitrates) contribute to poor visibility and impact public health. Major human health concerns associated with their exposure include effects on breathing and the respiratory system, damage to lung tissue, and premature death. In the environment, acid rain raises the acid levels in soils and water bodies (making the water unsuitable for some fish and other wildlife), and damages some trees at high elevations. It also speeds the decay of buildings, statues, and sculptures that are part of our national heritage.

Reductions in SO_2 and NOx have begun to greatly reduce these negative environmental effects and are leading to significant improvements in public health.

Visibility

Nature and Sources of the Problem. Visibility impairment is one of the most obvious effects of air pollution. Visibility impairment occurs as a result of the scattering and absorption of light by air pollution, including particles and gases. In addition to limiting the distance that we can see, the scattering and absorption of light caused by air pollution can also degrade the color, clarity, and contrast of scenes. The same particles that are linked to serious health effects can also significantly affect our ability to see.

Both the primary emissions and secondary formation of particles contribute to visibility impairment. “Primary” particles, such as dust from roads or elemental carbon (soot) from wood combustion, are emitted directly into the atmosphere. “Secondary” particles are formed in the atmosphere from primary gaseous emissions. Examples include sulfate, formed from sulfur dioxide (SO_2) power plant emissions and other industrial facilities; and nitrates, formed from nitrogen oxide (NOx) emissions from power plants, automobiles, and other types of combustion sources. In the eastern United States, reduced visibility is mainly attributable to secondarily formed sulfates. While these secondarily formed particles still account for a significant amount in the West, primary emissions from sources like wood smoke contribute a larger percentage of the total particulate loading than in the East.

Humidity can also significantly increase the effect of pollution on visibility. Some particles, such as sulfates, accumulate water and grow in size, becoming more efficient at scattering light and causing visibility impairment. Annual average relative humidity levels are 70 to 80 percent in the East as compared to 50 to 60 percent in the West. Poor summer visibility in the eastern United States is primarily the result of high sulfate concentrations combined with high humidity levels.

The Greenhouse Effect

The "Greenhouse Effect" occurs when the earth's atmosphere is warmed due to the reradiation and confinement of long-wave IR heat radiation.

The Greenhouse Effect or Global Climate Change is another environmental effect of air pollution. Under normal circumstances, solar radiation enters the earth's atmosphere where it is then transformed into heat radiation. Some of this radiation is absorbed, reflected, or reradiated within the earth's atmosphere. However, as atmospheric "greenhouse gases" increase, long-wave IR heat radiation is reradiated and trapped within the earth's atmosphere, eventually resulting in a warming of the earth's surface.

Recent scientific evidence shows that the greenhouse effect is being increased by the continued release of "greenhouse gases" into the atmosphere causing the Earth's temperature to rise. This is called "global warming." Carbon dioxide (CO_2) accounts for about 81 percent of greenhouse gases released in the United States. Carbon dioxide emissions are largely due to the combustion of fossil fuels in electric power generation, and the transportation and industrial sectors. Methane (CH_4) emissions, which result from agricultural activities, landfills, and other sources, are the next largest contributors to greenhouse gas emissions in the United States and worldwide.

Industrial processes such as foam production, refrigeration, dry cleaning, chemical manufacturing, and semiconductor manufacturing produce other greenhouse gas emissions, such as hydro fluorocarbons (HFCs). Smelting of aluminum produces another greenhouse gas called perfluorinated compounds (PFCs). While NOx and VOC emissions from automobile exhaust and industrial processes contribute to the formation of ground-level ozone or smog, also a greenhouse gas.

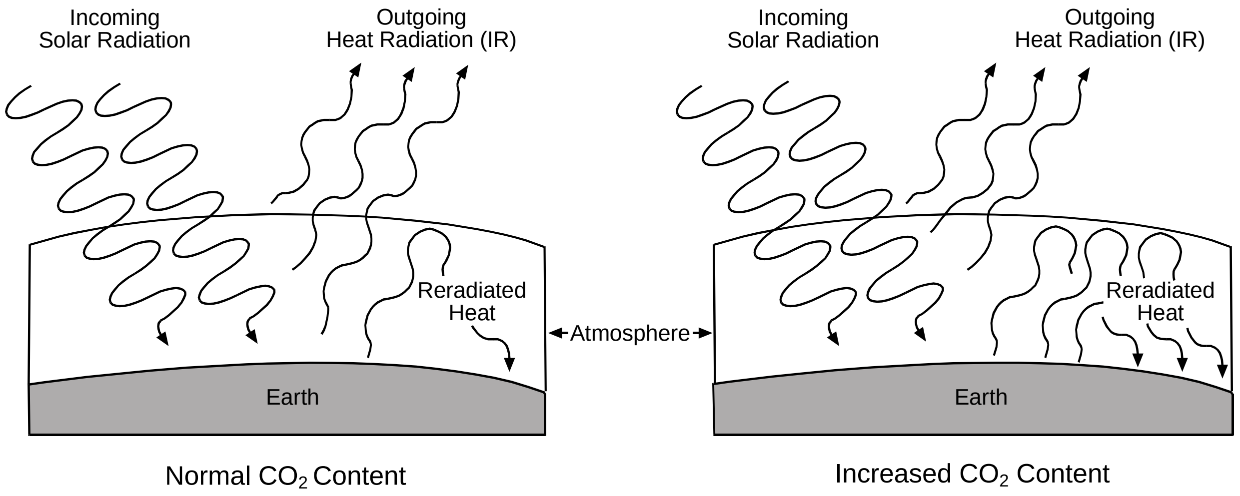


Figure 2-5. The Greenhouse Effect

Human Health and Environmental Effects. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was formed to assess the available scientific and economic information on climate change. In 1995, the IPCC published a report representing the work of more than 2,000 of the world's leading scientists. The IPCC concluded that humans are changing the Earth's climate, and that "climate change is likely to have wide-ranging and mostly adverse impacts on human health, with significant loss of life."

According to the IPCC, greenhouse gas emissions could cause a 2° to 6° Fahrenheit rise in temperature during the next century, if atmospheric levels are not reduced. Although this change may appear small, it could lead to more extreme weather events such as droughts and floods that may threaten coastal resources and wetlands by raising sea level. These effects could also increase the risk of certain diseases by producing new breeding sites for pests and pathogens. Agricultural regions and woodlands are also susceptible to changes in climate that could result in increased insect populations and plant disease. This degradation of natural ecosystems could ultimately lead to reduced biological diversity.

International Developments. In 1992, 150 countries signed the Framework Convention on Climate Change (FCCC), which has the objective of stabilizing the concentration of greenhouse gases in the atmosphere at levels that would prevent dangerous interference with the climate system. Under the FCCC, industrialized countries agreed to reduce greenhouse gas emissions to 1990 levels by the year 2000. However, most industrialized countries, including the United States, did not meet this target. In light of the 1995 scientific findings of the IPCC and the continued rise in greenhouse gas emissions, parties to the FCCC formulated the “Kyoto Protocol” at a 1997 conference held in Kyoto, Japan.

The Kyoto Protocol includes greenhouse gas emission targets for industrialized countries for the period of 2008–2012. The average reduction target for all industrialized countries for this period is 5 percent below 1990 emission levels. The reduction target varies across countries to account for differing circumstances, with the United States’ target being a 7 percent reduction below 1990 levels. The Kyoto Protocol also provides for market-based measures, such as international emissions trading, to help countries meet their commitments at the lowest possible cost. In 2001, the U.S. and other industrial countries rejected ratification of the Kyoto Protocol.

Stratospheric Ozone Depletion

Nature and Sources of the Problem. The stratosphere, located about 6 to 30 miles above the Earth, contains a layer of ozone gas that protects living organisms from harmful ultraviolet radiation (UV-b) from the sun. However, over the past two decades this protective shield has been damaged. Each year, an “ozone hole” forms over the Antarctic, and ozone levels fall to 70 percent below normal. Even over the United States, ozone levels are about 5 percent below normal in the summer and 10 percent below normal in the winter. Data today shows a trend of 3.4 percent decrease per decade in average total ozone over the northern hemisphere mid-latitudes since 1979.

Since 1979, scientists have recorded a 3.4% reduction in average total ozone over the mid-latitudes of the Northern Hemisphere.

As the ozone layer thins, more UV-b radiation reaches the Earth. In 1996, scientists demonstrated for the first time that UV-b levels over most populated areas have increased. In the 1970s, scientists had linked several substances associated with human activities to ozone depletion, including the use of chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform. These chemicals are emitted from commercial air conditioners, refrigerators, insulating foam, and other industrial processes. Strong winds carry them through the lower part of the atmosphere, called the troposphere, and into the stratosphere. There, strong solar radiation releases chlorine and bromine atoms that attack protective ozone molecules. Scientists estimate that one chlorine atom can destroy 100,000 ozone molecules.

Human Health and Environmental Effects. Some UV-b radiation reaches the Earth's surface even with normal ozone levels. However, because the ozone layer normally absorbs most UV-b radiation from the sun, ozone depletion is expected to lead to increases in harmful effects associated with UV-b radiation. In humans, UV-b radiation is linked to skin cancer, including melanoma, the form of skin cancer that has the highest fatality rate. UV-b also causes cataracts and suppression of the immune system.

The effects of UV-b radiation on plant and aquatic ecosystems are not well understood. However, the growth of certain food plants can be slowed by excessive UV-b radiation. In addition, some scientists suggest that marine phytoplankton, which are the base of the ocean food chain, are already under stress from UV-b radiation. This stress could have adverse consequences for human food supplies from the oceans. Because they absorb CO_2 from the atmosphere, significant harm to phytoplankton populations could increase global warming (see the following section on Global Warming and Climate Change).

Programs to Restore the Stratospheric Ozone Layer. In 1987, 27 countries signed the Montreal Protocol, a treaty that recognized the international nature of ozone depletion and committed the world to limiting the production of ozone-depleting substances. Today, over 170 nations have signed the Protocol, which has been strengthened five times and now calls for the elimination of those chemicals that deplete stratospheric ozone.

The Montreal Protocol and the 1990 Clean Air Act Amendments are two important programs designed to eliminate ozone-depleting substances such as CFCs, carbon tetrachloride, and methyl chloroform.

The 1990 Clean Air Act Amendments established a U.S. regulatory program to protect the stratospheric ozone layer. In January 1996, U.S. production of many ozone-depleting substances virtually ended, including CFCs, carbon tetrachloride, and methyl chloroform. Production of halons ended in January 1994. Many new products that either do not affect or are less damaging to the ozone layer are now gaining popularity. For example, computer-makers are using ozone-safe solvents to clean circuit boards, and automobile manufacturers are using HFC-134a, an ozone-safe refrigerant, in new motor vehicle air conditioners.

In some sectors, the transition away from ozone-depleting substances has already been completed. EPA is also emphasizing new efforts like the UV Index, a daily forecast of the strength of UV radiation people may be exposed to outdoors, to educate the public about the health risks of overexposure to UV radiation and the steps they can take to reduce those risks.

Trends in Stratospheric Ozone Depletion. Scientific evidence shows that the approach taken under the Montreal Protocol has been effective to date. In 1996, measurements showed that the concentrations of methyl chloroform had started to fall, indicating that emissions had been greatly reduced. Concentrations of other ozone-depleting substances in the upper layers of the atmosphere, like CFCs, are also beginning to decrease. It takes several years for these substances to reach the stratosphere and release chlorine and bromine. For this reason, stratospheric chlorine levels are expected to peak early in 2000, and then slowly decline. Because of the stability of most ozone-depleting substances, chlorine will be released into the stratosphere for many years, and the ozone layer will not fully recover until well into the century. All nations that signed the Protocol must complete implementation of ozone protection programs if full repair of the ozone layer is to occur.

Risk Assessment

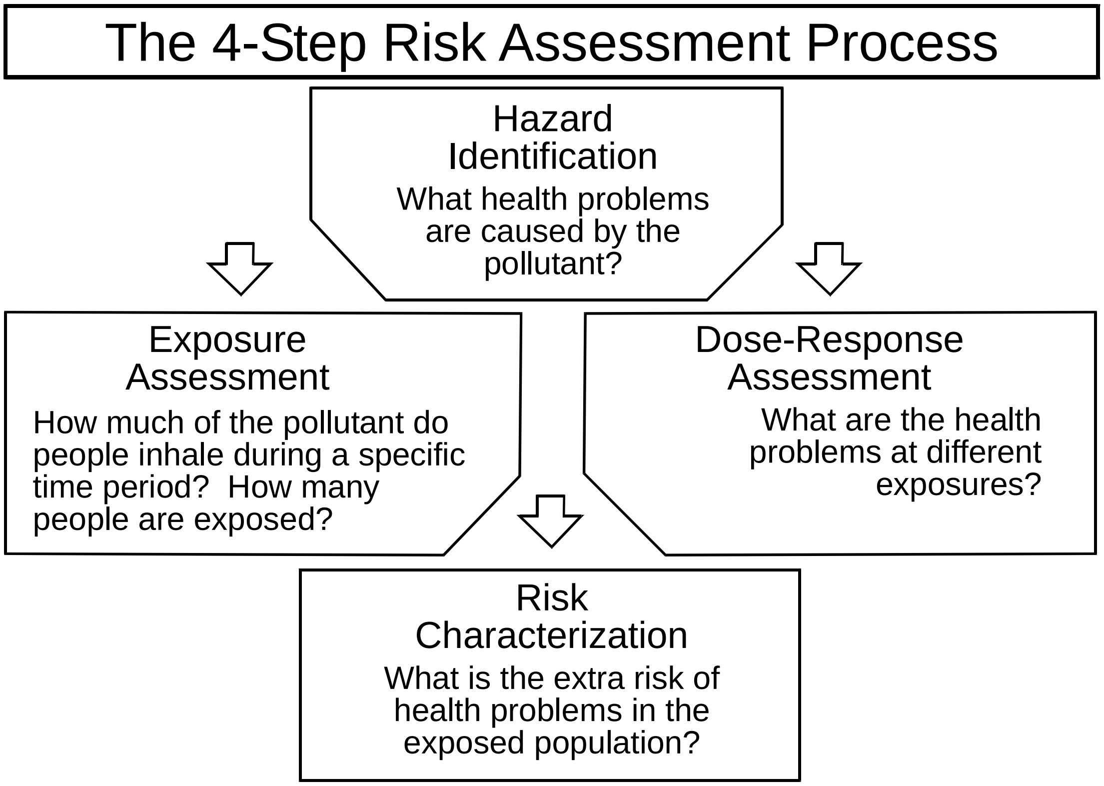
Health Risks. Health risks, put simply, are a measure of the chance that you will experience health problems. Exposure to toxic air pollutants can increase your health risks. For example, if you live near a factory that releases cancer-causing chemicals and inhale contaminated air, your risk of getting cancer can increase. Breathing air toxics could also increase your risk of non-cancer effects such as emphysema or reproductive disorders.

Risk management is the process the government uses to manage this health risk. Risk management uses this health risk information in concert with other non-risk factors, such as control options, to make decisions concerning the management of toxic air pollutants.

Risk Assessment. Risk assessment is one tool used in risk management. It is the process that scientists and government officials use to estimate the increased risk of health problems in people who are exposed to different amounts of toxic substances.

A risk assessment for a toxic air pollutant combines results of studies on the health effects of various animal and human exposures to the pollutant with results of studies that estimate the level of people's exposures at different distances from the source of the pollutant.

While the estimates provided by these risk assessments are far from perfect, they do help scientists evaluate the risks associated with emissions of toxic air pollutants. Using risk estimates and other factors, the government can set regulatory standards to reduce people's exposures to toxic air pollutants and reduce the risk of experiencing health problems.



What health problems are caused by the pollutant?

How much of the pollutant do people inhale during a specific time period? How many people are exposed?

What are the health problems at different exposures?

What is the extra risk of health problems in the exposed population?

Figure 2-6. The Risk Assessment Process

Hazard Identification. Hazard identification answers the question, “What health problems are caused by the toxic air pollutant?” The toxic air pollutants of greatest concern are those that cause serious health problems or affect many people. Health problems can include cancer, respiratory irritation, nervous system problems, and birth defects.

Some health problems occur very soon after a person inhales a toxic air pollutant. These immediate effects may be minor, such as watery eyes. Or they may be serious, such as life-threatening lung damage. Other health problems may not appear until many months or years after a person's first exposure to the toxic air pollutant. Cancer is one example of a delayed health problem.

In hazard identification, scientists evaluate all available information about the effects of a toxic air pollutant to estimate the likelihood that a chemical will cause a certain effect in humans. The better the evidence, the more certain scientists can be that a toxic air pollutant causes specific health problems. The amount, type, and quality of evidence are all important.

The best type of evidence comes from human studies. This evidence may be in the form of case reports, such as physicians' reports of an unusual number of cases of a specific illness. Other more formal studies can be done that compare the number of cases of a particular illness in groups of people with different levels of exposures (for example, cases of leukemia in rubber manufacturing workers).

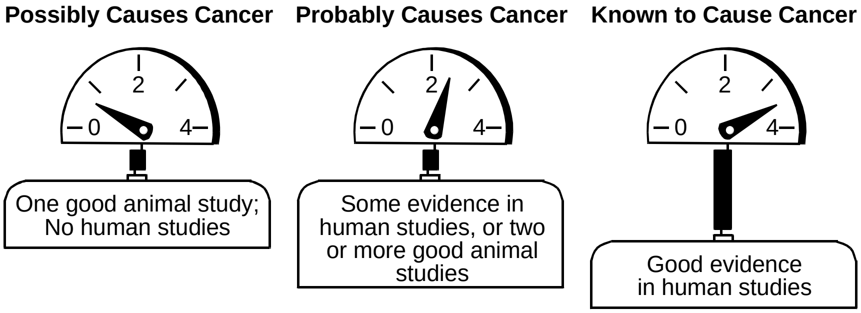


Figure 2-7. Pollutant Effect, Human and Animal Studies

Because human information is very limited for most toxic air pollutants, scientists often conduct studies on laboratory animals, such as rats. Animal studies are performed under controlled laboratory conditions. Scientists can study a variety of health effects by exposing animals to pollutants at varied concentrations and for varied time periods. When relying on animal studies only, scientists need to be satisfied that health effects in humans are likely to be the same as those in the animals tested. In order to maximize the validity of the study, scientists try to use animal species with body functions that are similar to humans.

Pollutant exposure is the extent or degree to which a receptor may have contact with a chemical, physical, or biological agent.

Exposure Assessment. Another element of the risk assessment process is to consider how exposure to various pollutants affects human health and the environment. Pollutant exposure is the extent or degree to which a receptor may have contact with a chemical, physical, or biological agent. Exposure occurs in many ways such as ingestion, inhalation, absorption, or injection. Regardless of how a receptor is ultimately exposed, the hazardous effect that exposure has on a receptor is greatly compounded by the amount or concentration of a pollutant and the frequency or number of times it is exposed. Duration, or the period of exposure, also plays an important role in the severity of the final effect.

Therefore, exposure assessment answers the question about how many pollutants are inhaled by people over a specific time period, as well as how many people are exposed. Ultimately, the hazardous effect of air pollution on human health and the environment is based on a complex relationship between receptor, dose, toxicity, and exposure. Attempts to quantify or qualify the behavior of pollutants on public health or the environment must be done with an understanding of this principle.

Ambient air monitors and computer models are used to estimate the amount of pollution released from a source.

There are many sources of toxic air pollutants. For example, a factory smokestack or thousands of automobiles crossing a busy intersection each day could be the source of a pollutant of concern. So the first step in an exposure assessment is to decide which sources are giving off the pollutant of concern.

Once the identity and location of the sources are known, the next step is to determine the amounts of the toxic air pollutant released in a specific time period and how it moves away from the sources. Engineers use either monitors or computer models to estimate the amount of each pollutant released from the source and the amount of these pollutants at different distances from the source. Monitors are used to sample the air and measure how much of the pollutant is present. Computer models use mathematical equations that represent the processes that occur when a facility releases a pollutant and also the movement of pollutants through the air. Factors such as distance from the source to exposed persons, wind speed and direction, and smokestack height affect these estimates.

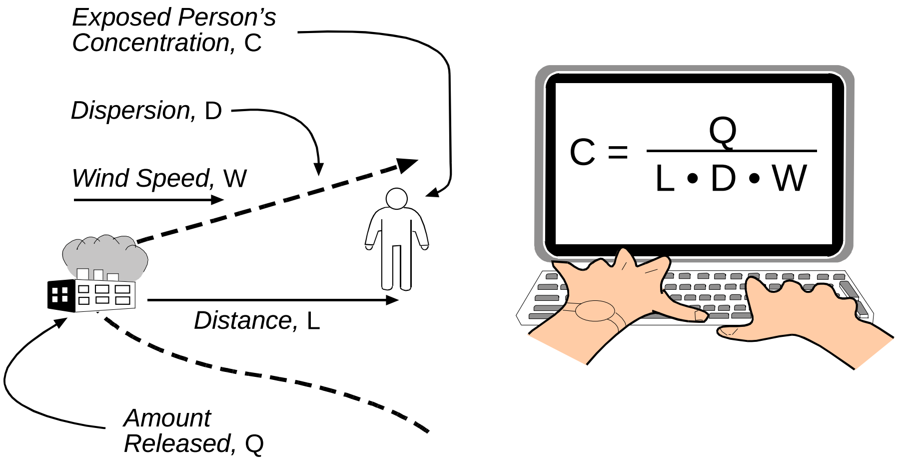


Figure 2-8. Exposure Modeling Factors

The number of people exposed at different distances from the site of release can be estimated with computer models that use information from the census and from maps. Some models can even estimate exposures for the different places people are each day – including indoor, automobile, outdoor, and workplace exposures.

The final step in an exposure assessment is to estimate the amount of pollution each person inhales. To do this, scientists combine estimates of breathing rates and the lifespan of an average person with estimates of the amount of pollutant in that person's air.

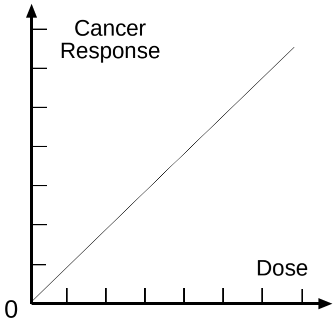


Fig. 2-9. Dose-Response Relationship for Cancer

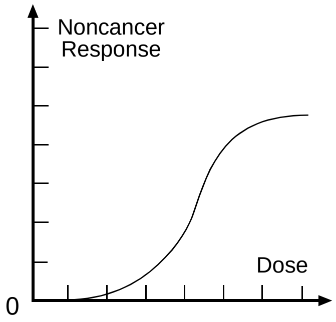


Fig. 2-10. Dose-Response Relationship for Non-Cancer Effects

Dose-Response Assessment. Dose-response answers the question, “What are the health problems at different exposures?” The dose-response relationship for a specific pollutant describes the association between exposure and the observed response (health effect). In other words, it estimates how different levels of exposure to a pollutant change the likelihood and severity of health effects. Just as in the hazard identification, scientists use results of animal and human studies to establish dose-response relationships.

In the absence of clear evidence to the contrary, EPA assumes there are no exposures that have "zero risk"—even a very low exposure to a cancer-causing pollutant can increase the risk of cancer (albeit a small amount). EPA also assumes that the relationship between dose and response is a straight line for each unit of increase in exposure (dose), there is a corresponding increase in cancer response.

A dose may exist below the minimum health effect level for which no adverse effects occur. But EPA typically assumes that at low doses the body's natural protective mechanisms repair any damage caused by the pollutant, so there is no ill effect at low doses. However, for some substances non-cancer effects may occur at low doses. The dose-response relationship (the response occurring with increasing dose) varies with pollutant, individual sensitivity, and type of health effect.

Risk Characterization. Risk characterization addresses the question, “What is the extra risk to health?” Risk information is presented in different ways to illustrate how individuals or populations may be affected. Some of the most common risk measures are described here.

Maximum Individual Lifetime Cancer Risks: Combining the results of the exposure assessment and the dose-response assessment gives an estimate of the increased lifetime risk of cancer for an individual exposed to the maximum predicted long-term concentration.

Maximum Lifetime Exposure	X	Dose-Response Relationship	=	Maximum Lifetime Exposure

Distribution of Individual Risks: Many people may be exposed to less than the maximum level. Depending on the amount of exposure, an individual's risk of cancer will vary. The distribution of individual risk is usually expressed as the number of people estimated to be at various levels of risk.

Population Cancer Risks: Distributions of individual risk are used to calculate population risk. The population cancer risk is usually expressed as the expected increased incidence of cancer (that is, the number of new cases each year) for all people exposed to the pollutant. For example, the estimated population cancer risk may be the number of new cancer cases per year expected among residents within 30 miles of a certain large source.

Non-cancer Risks: Health reference levels refer to exposure levels that will not cause significant risks of non-cancer health effects. Long-term exposure to levels below these levels is assumed to produce no ill effects.

Health reference levels are an example of one index that government agencies use in characterizing non-cancer health risks. These levels are generally developed from exposure levels that do not produce ill effects in experimental animals. These exposure levels are adjusted to account for animal-human differences (such as breathing rate) and for underlying uncertainties (such as the difference in sensitivity between healthy adults and more sensitive people like children and the elderly).

Risk analysts then compare the health reference levels with the exposure estimates to determine how many people are exposed to concentrations higher than the health reference level. Some of these people might experience ill effects.

Uncertainty of Risk Estimates. Although scientists can estimate risks caused by toxic air pollutants in animals experimentally or in humans who have unusual exposures, converting these estimates to those expected in people under a wide range of conditions is difficult, and can be misleading.

By their nature, risk estimates cannot be completely accurate. The main problem is that scientists don't have enough information on actual exposure and on how toxic air pollutants harm human cells. The exposure assessment often relies on computer models when the amount of pollutant getting from the source to people cannot be easily measured. Dose-response relationships often rely on assumptions about the effects of pollutants on cells for converting results of animal experiments at high doses to human exposures at low doses. When information is missing or uncertain, risk analysts generally make assumptions that tend to prevent them from underestimating the potential risk—that is, these assumptions provide a margin of safety in the protection of human health.

NAME ______________________________ DATE __________________ SCORE _________

CHAPTER 2 HUMAN HEALTH AND ENVIRONMENTAL EFFECTS

Multiple Choice

Directions: Read each question and choose the best answer. Write the letter of your answer in the space provided.

1. The human health effect that best describes carbon monoxide (CO) poisoning is __________.

a. accumulation of toxins in the bones and soft tissue resulting in renal failure
b. increased airway resistance resulting in bronchial constrictions
c. interference with the body's ability to supply oxygen to tissue resulting in cardiovascular disease
d. inflammation of the lungs resulting in emphysema or fibrosis
e. development of phagocyte cells resulting in chronic bronchitis **1.** ________

2. Each of the following is a direct effect of air pollution on the respiratory system, **except** __________.

a. pulmonary emphysema
b. lung cancer
c. pneumoconiosis
d. chest pain
e. blood poisoning **2.** ________

3. Which of the following is a part of the risk assessment process?

a. Hazard Identification
b. Dose-Response Data
c. Exposure Assessment
d. Risk Characterization
e. All of the above. **3.** ________

4. ____________ accounts for most of the total SO_2 emissions.

a. Petroleum refining
b. Sulfuric Acid Manufacturing
c. Fuel combustion
d. Smelting **4.** ________

Matching

Directions: *Match the environmental effect that best applies to the categories listed and record the letter in the space provided. Each category may be used more than one time.*

A. Environmental Effects of Air Pollution

________ **5.** Acidification of lakes and streams

________ **6.** Pristine vistas and national parks irreparably altered

________ **7.** Soiled buildings, clothing, and automobiles.

________ **8.** Melting snow and ice at both poles

________ **9.** Cracked and split rubber products, nylon, and polymer plastics

_______ **10.** Damage to vegetation, forests, and crops

_______ **11.** Variations in annual and seasonal precipitation patterns

_______ **12.** Reduction in open-air visibility

a. Ecosystem Damage
b. Global Warming
c. Property Damage
d. Quality of Life

Directions: *Match the human system or organ that is most directly affected by the criteria pollutants listed and record the letter in the space provided. (5 points)*

B. Human Health Effects of Air Pollution

_______ **13.** Respiratory System

_______ **14.** Reduced Lung Elasticity

_______ **15.** Lower Respiratory System

_______ **16.** Circulatory System

_______ **17.** Lowered Resistance to Infection

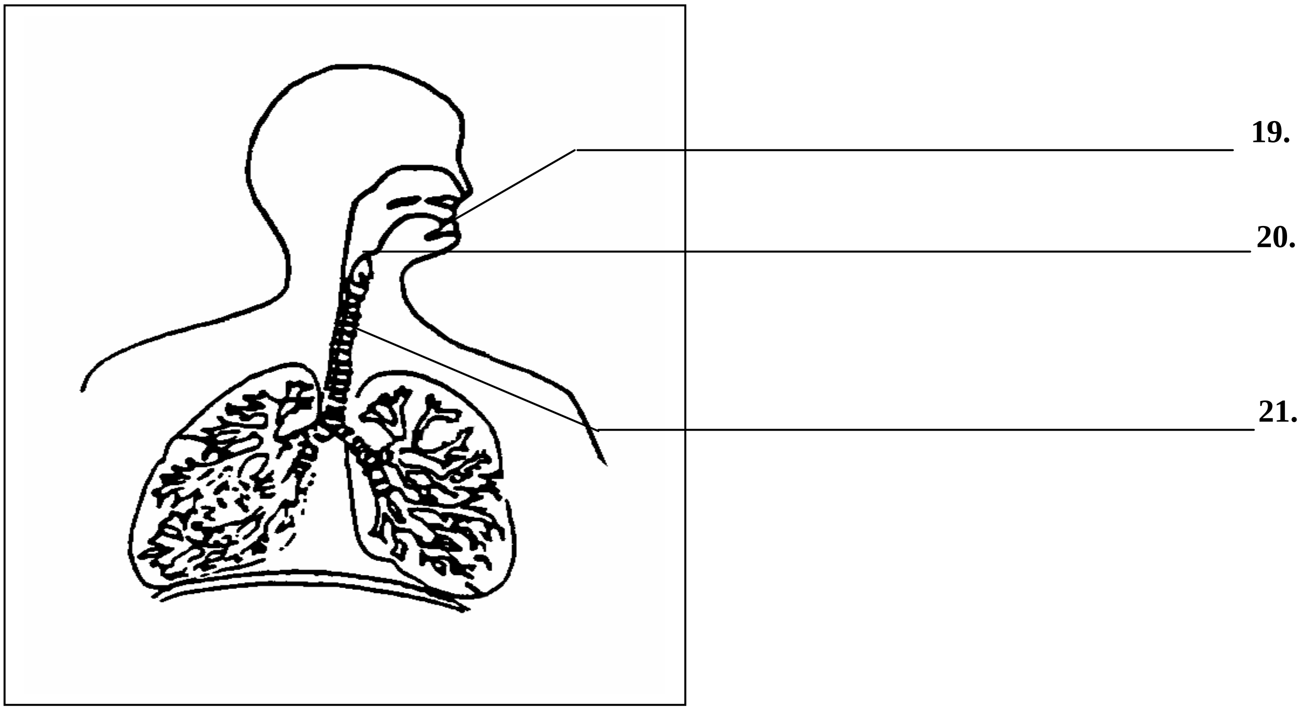
_______ **18.** Organs and Soft Tissue

e. Particulate Matter (PM)
f. Lead (Pb)
g. Sulfur Dioxide (SO_2)
h. Carbon Monoxide (CO)
i. Nitrogen Dioxide (NO_2)
j. Ozone

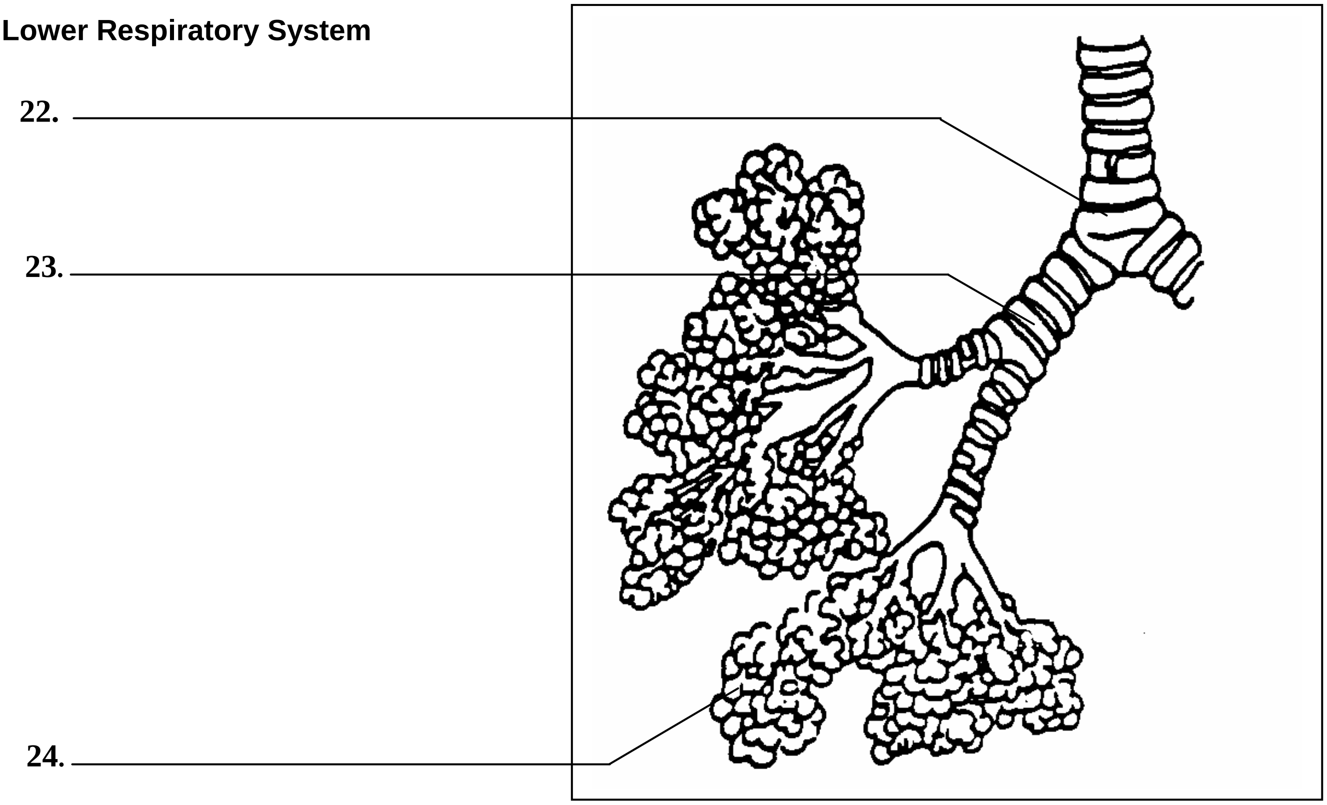
Diagramming

Directions: Diagram the following parts of the human body.

A. Upper Respiratory System



B. Lower Respiratory System



REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	C	2-11
2.	E	2-7
3.	E	2-25
4.	C	2-11
5.	A	
6.	D	
7.	C	
8.	B	
9.	C	
10.	A	
11.	B	
12.	D	
13.	G	
14.	J	
15.	E	
16.	H	
17.	I	
18.	F	
19.	Tongue	2-5
20.	Larynx	
21.	Trachea	
22.	Bronchi	2-6
23.	Bronchiole	
24.	Alveoli	

CHAPTER 3

Transport and Dispersion of Air Pollution

Lesson Goal

Demonstrate an understanding of the meteorological factors that influence wind and turbulence, the relationship of air current stability, and the effect of each of these factors on air pollution transport and dispersion; understand the role of topography and its influence on air pollution, by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Describe the various methods of air pollution transport and dispersion.
2. Explain how dispersion modeling is used in Air Quality Management (AQM).
3. Identify the four major meteorological factors that affect pollution dispersion.
4. Identify three types of atmospheric stability.
5. Distinguish between two types of turbulence and indicate the cause of each.
6. Identify the four types of topographical features that commonly affect pollutant dispersion.

Recommended Reading: Godish, Thad, "The Atmosphere," "Atmospheric Pollutants," "Dispersion," and "Atmospheric Effects," *Air Quality*, 3rd Edition, New York: Lewis, 1997, pp. 1-22, 23-70, 71-92, and 93-136.

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Wanta, Raymond C. and William P. Lowery, “The Meteorological Setting for Dispersal of Air Pollutants,” A.C. Stern (Ed.), *Air* Pollution, Vol*. I.*, *Air Pollutants, Their Transformation and*

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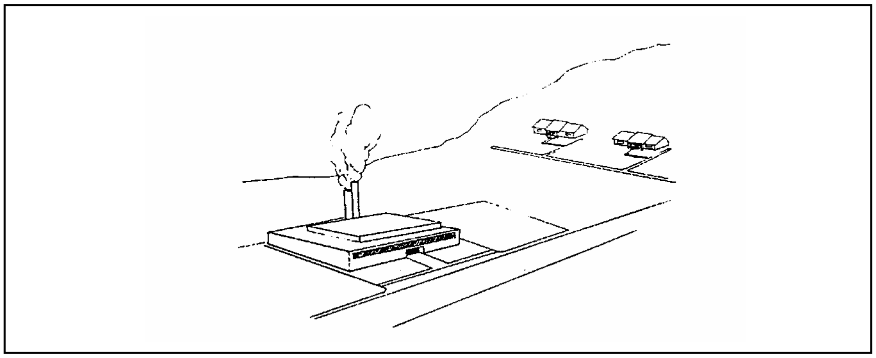
Transport and Dispersion of Air Pollution

Air pollution meteorology is the study of how pollutants are delivered and dispersed into the ambient air (Wanta, 1977). The environmental scientist is particularly interested in the data obtained from dispersion modeling because it provides critical information about the fate and effect of pollutants upon human health and the environment. In fact, the ability to predict the behavior of pollution in the ambient air is essential when attempting to manage and control its impact.



Air Pollution meteorology studies how pollutants are delivered and dispersed into the ambient air.

Knowledge of air pollution meteorology is essential to air quality planning activities. Understanding the way air pollution is transported and dispersed may indicate where to properly locate air pollution monitoring stations. Meteorological data may also be used to develop implementation plans and predict the atmospheric processes that will ultimately affect an area’s ability to comply with National Ambient Air Quality Standards (NAAQS). The purpose of this chapter is to introduce you to the atmospheric and topographical factors that influence nature’s ability to transport and disperse air pollution.

Wind Speed

High wind speeds result in lower pollutant concentrations.

A principle feature of atmospheric circulation is wind speed or velocity. Air movement associated with the horizontal motion of the atmosphere is commonly called wind and significantly affects pollutant concentration. In general, the higher the wind's velocity, the lower the pollutant concentration will be. In this sense, wind speed not only hastens pollutant dispersion, but also dilutes it (Godish, 1977).

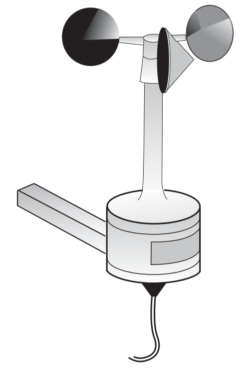


Fig. 3-1. Rotating Cup Anemometer

Wind speed can be measured in many ways, but two of the most common instruments used to measure wind velocity are the rotating cup and propeller anemometers. The rotating cup anemometer is more accurate and usually consists of three cone-shaped cups mounted symmetrically on a vertical axis. Propeller anemometers are characterized by a two-, three-, or four-bladed propeller attached to a vane and mounted on a vertical shaft. While both anemometers can effectively measure horizontal wind speed and direction, an additional propeller must be mounted perpendicular to the axis in order to measure vertical drafts of wind (Hewson, 1976).

Wind Direction

Seasonal wind patterns identify communities that may be vulnerable to pollutant exposure.

Another important factor of air pollution transport and dispersion is wind direction. A sophisticated network of air pollution monitoring stations have been created to record seasonal wind patterns and prepare streamline maps that help predict, with relative accuracy, the transport of pollution at specific times or seasons throughout the year. Analysis of seasonal wind patterns helps industrial planners to locate sources of air pollution in optimal locations in order to minimize their effect upon surrounding communities or the environment.

In urban areas, for example, a record of wind direction is used to estimate average concentrations of hydrocarbons, sulfur dioxide, and other pollutants. Recent research indicates that urban pollutants such as NO_2, SO_2, and O_3 are of the most concern. Chronic lung disease is attributed to NO_2 levels at just 50 ppm and can be lethal at 150 ppm. Urban measurements of SO_2 at 0.05 ppm can result in respiratory complications, and high concentrations of O_3 (0.01 ppm) have been found to result in significant changes in lung function among school children (Lyons and Scott, 1990). For this reason, it is extremely important to properly manage the formation and release of these air pollutants in urban-industrial settings where dense populations quickly multiply their effect upon human health.

The direction of airflow is also measured by the wind vane of the anemometer and recorded on a wind rose. A wind rose is a diagram designed to depict the relative frequency with which the wind blows from the various directions around the compass. Specific information can be recorded for seasonal wind patterns as well as local fluctuations by time of day. The diurnal wind rose records classic atmospheric weather patterns on a monthly seasonal basis. The lapse (daytime) and inversion (nighttime) wind roses record major differences in wind direction by time of day. Plotting daily and seasonal concentrations of air pollution in this manner is an invaluable way to help identify sources of pollution and evaluate their impact upon air quality.

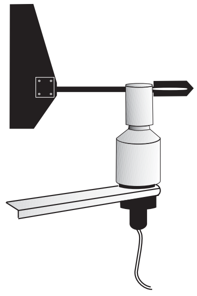


Fig. 3-2. Wind Direction Vane

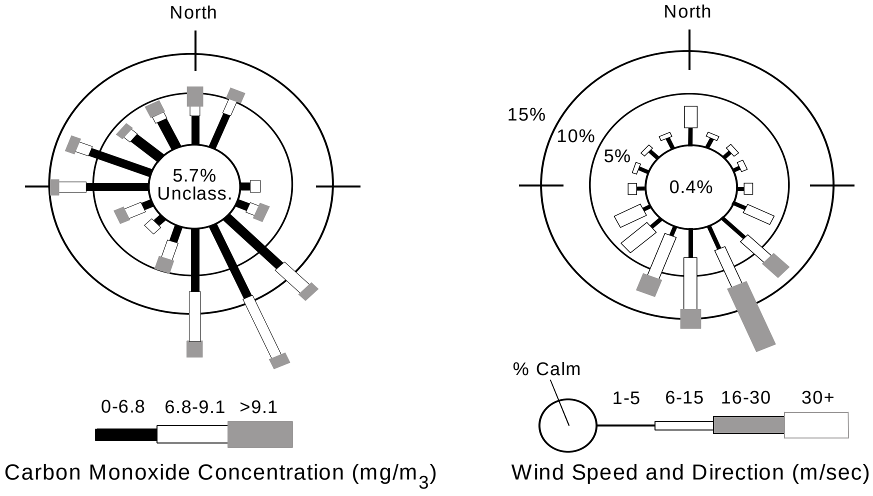


Fig. 3-3. Air Pollution Rose (l.) and Wind Rose (r.)

Information for eight primary and eight secondary directions of the compass are shown in Figure 3.3. The length of the wind rose spokes indicates wind direction frequency. The center of the diagram shows the frequency of calms and the individual segments represents the frequency of wind speed in the identified range. As shown in the Figure 3.3(l), the prevailing wind is Southeast (SE) and the wind direction of least frequency is East (E). A wind rose can be made for any time of the day, and it can represent the wind direction for any month or season of the year. Wind roses can also be utilized to track or predict dispersion of pollutants and odors from point or area sources. A pollution rose can also be constructed to indicate the frequency of measured or predicted levels of a pollutant, as a function of wind direction (see Figure 3.3(r).)

Atmospheric Stability

Stable atmospheric conditions usually occur when warm air is above cooler air, inhibiting vertical mixing. This condition is commonly referred to as an atmospheric inversion.

While wind speed and direction generally relate to the horizontal movement of air, atmospheric stability relates to the forces that move air vertically. The vertical movement of air, or atmospheric stability, is most directly affected by high- and low-pressure systems that lift air over terrain and mix it with the upper atmosphere. The mechanisms that are specifically responsible for the vertical movement of air are atmospheric temperature and pressure. Everything on earth absorbs, stores and reradiates the sun’s energy. Some parts of the earth, or different types of surfaces heat more readily than others. This is known as differential heating. For example, a plowed field heats more quickly than a large lake, which can store large amounts of energy, but heat up slower.

Differential heating of the earth affects the air above it. The air directly above a heated surface will also become heated as the heat moves to an area of less heat. This warming occurs due to two basic principles; conduction and convection. Conduction is the transfer of heat that takes place when something touches a heated surface. In this case, the air touches the heated earth and gains some of that heat. Convection is the vertical mixing of the air.

A parcel of air, for example, that is warmer than the surrounding air masses will expand, rise and cool. As the air expands, it decreases in both temperature and pressure. A parcel of cool air, however, behaves in the opposite manner.

As warm air rises, it cools; as cool air descends, it warms.

Air circulates on the earth in a three-dimensionally movement not only vertically and horizontally. This movement is called turbulence. Turbulence occurs from two different processes: (1) *mechanical or* (2) *thermal turbulence.* Thermal turbulence results from atmospheric heating and mechanical turbulence from the movement of air past an obstruction. Both types of turbulence usually occur in during any atmospheric air movements, although one type or the other may dominate under certain circumstances. For example; on clear sunny days with light winds, thermal turbulence is dominant. Where as, mechanical turbulence is dominant on windy night with neutral atmospheric stability. The net effect of turbulence is to enhance the pollutant dispersion process. However, mechanical turbulence can cause downwash from a pollution source, which can result in high concentrations of pollutants, immediately downwind.

Adiabatic and Environmental Lapse Rate

The temperature in the troposphere decreases with height up to an elevation of about 10 kilometers. Decreasing temperature with height is described as the lapse rate. On average this decrease is –0.65°C/100 m and is stated as the normal lapse rate. If a parcel of air were lifted in the atmosphere, then allowed to expand and cool or compress and warm, with a change in atmospheric pressure and no interchange of heat, it would be an adiabatic process. The air parcel must also be unsaturated and the rate of adiabatic cooling or warming remains constant. The rate of heating or cooling for unsaturated air is 10°C/1000 meters, with the water remaining in the gaseous state, and is referred as the dry adiabatic lapse rate.

Individual vertical temperature measurements can vary considerably from either the normal or dry adiabatic lapse rate. This change of temperature with height for a specific measured location is the environmental lapse rate. The environmental lapse rate values characterize the atmospheric stability and have a direct bearing on the vertical air movement and pollutant dispersion (Godish, 1997).

A critical relationship exists between atmospheric stability and pollutant concentrations. Pollutants that cannot be

Types of Smokestack Plumes:

- *Looping*
- *Fanning*
- *Coning*
- *Lofting*
- *Trapping*
- *Fumigating*

transported or dispersed into the upper atmosphere quickly become trapped at ground level and pose a significant risk to human health and the environment. This relationship can be visualized in the behavior of emission plumes from industrial smoke stacks. Six types of air pollution plumes illustrate the relationship between atmospheric stability and pollutant emissions: looping plumes, fanning plumes, coning plumes, lofting plumes, fumigating plumes, and trapping plumes.

Looping plumes. Pollution that is released into an *unstable* atmosphere forms looping plumes. Rapid changes in temperature and pressure may result in plumes that appear billowing and puffy. While unstable conditions are usually favorable for pollutant dispersion, high concentrations of air pollution forced down by cooling air can be harmful if trapped at ground level. This can occur on sunny days with light to moderate winds, which combine with rising and sinking air to cause the stack gases to move up and down in a wavy pattern producing a looping plume (Godish, 1997).

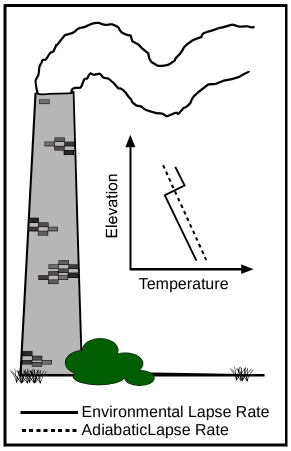


Fig. 3-4. Looping Plume

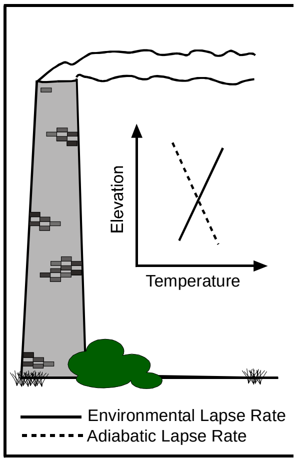


Fig. 3-5. Fanning Plume

Fanning plumes. A fanning plume occurs during *stable* conditions and is characterized by long, flat streams of pollutant emissions. Because atmospheric pressure is stable, there is neither a tendency for emissions to rise nor descend permitting (horizontal) wind velocity to transport and disperse the pollutant. Fanning plumes are usually seen during the early morning hours just before the sun begins to warm the atmosphere and winds are light (Godish, 1997).

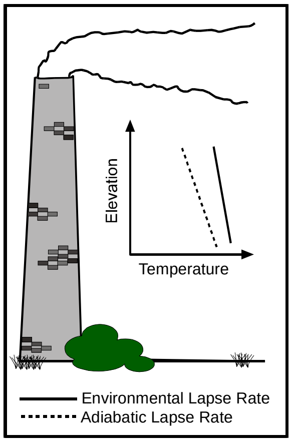


Fig. 3-6. Coning Plume

Coning plumes. *Neutral* or slightly unstable conditions create a coning plume that is distinguished by large billows or puffs of pollutants. Coning plumes are typically formed on partly cloudy days when there is an alternate warming and cooling of the atmosphere. Warm gases released into cool, ambient air mix, expand, and rise into the upper atmosphere (Godish, 1977).

Lofting plumes. When the atmosphere is relatively *stable*, warm air remains above cool air and creates an inversion layer. Pollutants released below the inversion layer will remain trapped at ground level and, in the absence of any atmospheric instability, prevent the upward transport of the pollutant. When there is little or no vertical mixing, pollutants tend to form in high concentrations at ground level. When conditions are unstable or neutral above the inversion layer, stack gases above that level form a lofting plume that can effectively disperse the pollutant into the upper atmosphere (Godish, 1997).

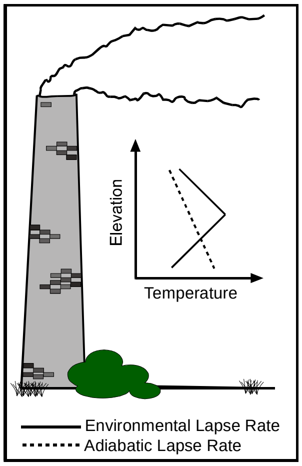


Fig. 3-7. Lofting Plume

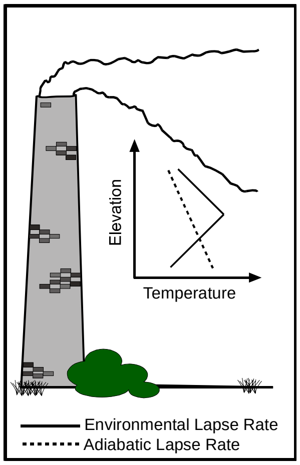


Fig. 3-8. Fumigating Plume

Fumigating plumes. In the early morning, if the plume is released just below the inversion layer, a very serious air pollution episode could develop. When pollutants are released below the inversion layer, gaseous emissions quickly cool and descend to ground level. This condition is known as fumigation and results in a high concentration of pollution that can be damaging to both humans and the environment alike. This atmospheric condition characterizes the most destructive type of air pollution episode possible

(Godish, 1997).

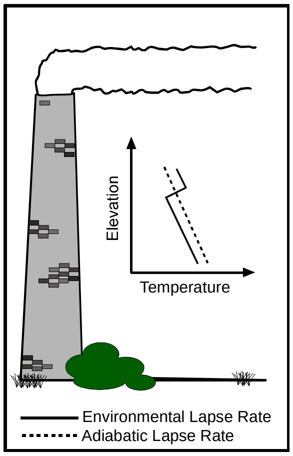
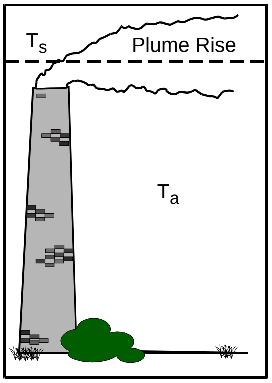
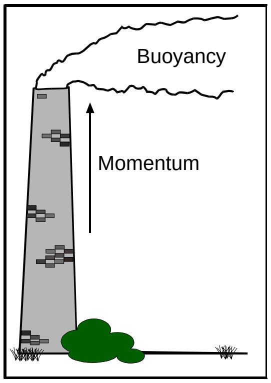


Fig. 3-9. Trapping Plume

Trapping plumes. A trapped plume, on the other hand, is produced on clear, sunny days or clear nights with light winds. A trapped plume is the result of an *unstable* air mass that creates an inversion layer both above and below the plume. A trapped plume, in contrasted with a fumigating plume, is one of the most favorable types of plume for pollutant dispersion. Temperature inversions, both above and below the plume, protect ground sources from potential exposure while winds at altitude disperse and dilute the pollutant (Godish, 1997).

Plume Rise

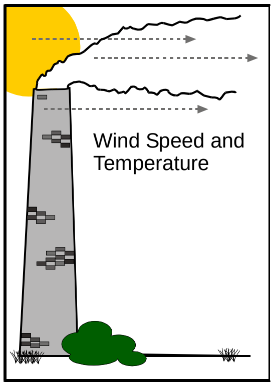




As you observe smoke from a stack, you will notice that the smoke usually rises above the top of the stack. The distance that the plume rises above the stack is called *plume rise.* It is actually calculated as the distance to the imaginary centerline of the plume rather than to the upper or lower edge of the plume. Plume rise, Δh, depends on the stack's physical characteristics. For example, the effluent characteristic of stack temperature in relation to the surrounding air temperature is more important than the stack characteristic of height. The difference in temperature between the stack gas (T_S) and the ambient air (T_a) determine plume density and that density affects plume rise. Therefore, smoke from a short stack could climb just as high as smoke from a taller stack.

Stack characteristics are used to determine momentum, and effluent characteristics are used to determine buoyancy. The stack provides the initial momentum of the effluent. It is determined by the speed of the effluent as it exits the stack. As momentum carries the effluent out of the stack, atmospheric conditions begin to affect the plume.

The condition of the atmosphere, including the winds and temperature profile along the path of the plume, will largely determine the plume's rise. As the plume rises from the stack, the wind speed across the stack top begins to tilt the plume. Wind speed usually increases with distance above the earth's surface. As the plume continues upward the stronger winds tilt the plume even farther. This process continues until the plume appears to be horizontal to the ground. The point where the plume to be appears to be horizontal may be a considerable distance downwind from the stack. The stronger the wind, the faster the plume will tilt over.



Topography

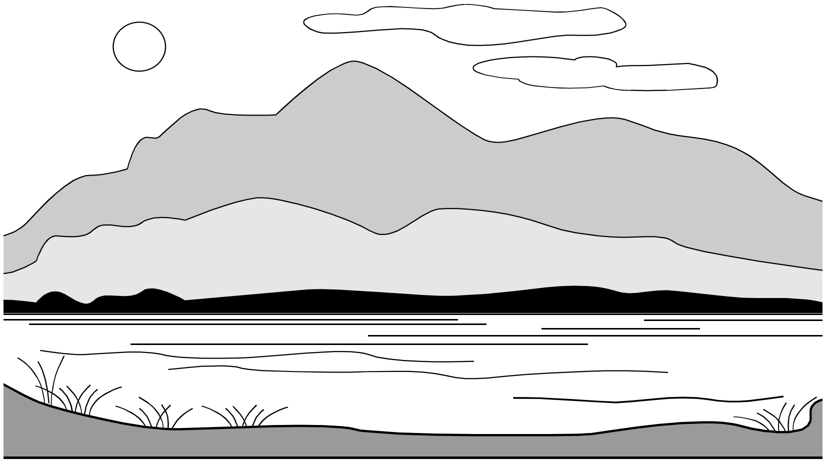
Another factor that affects the transport and dispersion of air pollution is topography. Topography is simply the representation of surface features such as mountains, hills, rivers, and valleys. For example, the location of an urban area in or around a mountain range can create significant pollution problems for the population. While horizontal and vertical airflow can be conducive to pollutant dispersion, a mountain range becomes a natural barrier.

Valleys. In addition, air has a natural tendency to flow downhill and accumulate in a valley floor in much the same manner as water. As cool, dense air descends into a valley, large populations may be put at great risk for excessive exposure to pollutants. When this natural flow of cool air is accompanied by a temperature inversion, the effect upon human health can be catastrophic. In some valleys the inversion layer can be several hundred meters thick, resulting in air pollution being trapped at ground level.

Natural and man-made topographical features can significantly affect the transport and dispersion of air pollution.

Lakes and Oceans. Large bodies of water also affect the transport and dispersion of air pollution. Air that is located over land heats more rapidly than lakes and oceans, which absorbs more heat, but at a slower rate. As the heated air rises into the upper atmosphere, it cools and tends to migrate toward other cold air masses, most of which are found over large bodies of water. This cycle begins as a warm parcel of air settles over water, rapidly cools, and creates a weak circulation cell. The cycle is completed during hours of darkness as sea breezes recycle air back toward the cooling landmasses.

Mountains. Los Angeles, Denver, and Mexico City are examples of locations that all experience high concentrations of pollution simply because they are located in natural basins bordered by mountain ranges (Godish, 1997). Although many other factors contribute to the air pollution problems in these cities, the topography of the surrounding area has a significant and unyielding influence. Even under the most favorable atmospheric conditions, natural barriers such as mountain ranges easily trap escaping pollutants. Although little can be done to overcome the effects of topographic features, intelligent planning that relies on recorded information regarding seasonal patterns of wind speed and direction, atmospheric stability, and topography can significantly reduce the harmful effects of air pollution on population centers.



Dispersion Modeling

Dispersion modeling is a tool used by environmental scientists to predict patterns of air pollution transport and dispersion.

Wind speed and direction, atmospheric stability, plume rise and topography interact in complex ways to cause the transport and dispersion of air pollution. Pollutant dispersion modeling was created as a comprehensive means of viewing the results of these complex interactions, collecting data attributable to various elements, both natural and man-made, and estimating the amount of ground-level pollution at various distances from the source. *Modeling*, therefore, is a mathematical representation of pollutant dispersion and the factors that influence it. As an extension of these mathematic representations, scientists also use computer modeling to produce graphic representations of the transport and dispersion of air pollution.

In order to develop a precise model or method to illustrate the manner in which air pollution is transported and dispersed for a given locale, information about the pollutant source is needed. This information generally includes surrounding geographic features, features, quantity and types of pollutants emitted, effluent gas conditions, stack height, and influential meteorological factors. Using these types of data as input for a computer model, scientists can effectively predict how pollutants will be dispersed into the atmosphere. In addition, levels of pollutant concentration can be estimated for various distances and directions from the site of the smokestack.

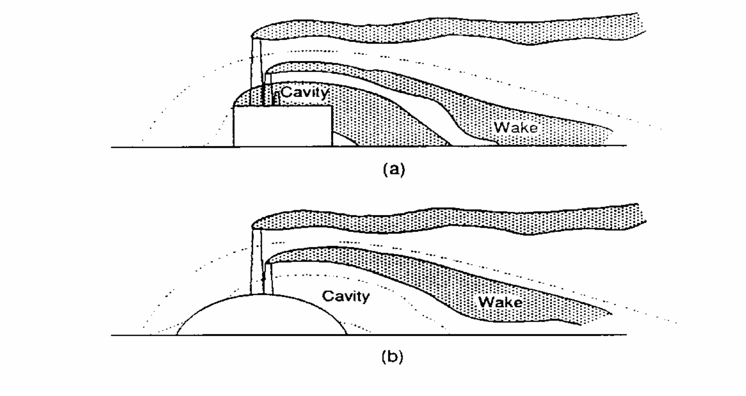


Fig. 3-10. Types of Pollutant Dispersion

Types of Pollutant Dispersion:

(a) Distribution of pollutants injected within and outside the air cavity.

(b) The effect of streamlining an obstacle during the design phase of an effluent stack.

U.S. environmental regulations have been formalized into a series of procedures that deal with permitting requirements that can affect both existing and new industrial facilities. Within this permitting process the use of selected air pollution dispersion models can aid in the determination of whether a specific facility should be constructed, modified based on the submitted plans, or need more efficient controls to be in compliance. An important advantage in the application of air pollution models for permitting is that the same set of procedures is applied for all One of the most important regulatory processes is the process of evaluating an application for a “permit to construct” or a New applicants. This allows an objective evaluation of air quality impact generated by the proposed or modified pollutant emitting facility.

Air dispersion modeling is utilized extensively in the permitting process for new and existing industrial facilities. For New Source Review (NSR) requirements, dispersion modeling can determine whether the proposed source will exceed its part of an allowable air increment within the facilities Air Quality Management Area.

New Source Review (NSR). The NSR process can vary depending on the new source location. If the area where the new plant is being located is attainment for all National Ambient Air Quality Standard Criteria pollutants, then the facility is subject to the Prevention of Significant Deterioration (PSD) doctrine. The PSD review process uses an appropriate dispersion model to evaluate whether the proposed source will exceed its part of the allowable air increment within the sites' AQM area.

40 CFR Part 51 contains guidelines on use of air quality modeling. Gaussian models as described in these guidelines are the most widely used technique for estimating the impact of non-reactive pollutants.

Guidelines on air quality modeling are found in 40 CFR Part 51 Appendix W. The air quality modeling procedures discussed in the guideline document can be categorized into four generic classes: Gaussian, numerical, statistical or empirical, and physical.

Within these classes, especially Gaussian and numerical models, a large number of individual "computational algorithms" may exist, each with its own specific applications. While each of the algorithms may have the same generic basis, it is accepted practice to refer to them individually as models. Gaussian models are the most widely used techniques for estimating the impact of non-reactive pollutants.

Numerical models may be more appropriate than Gaussian models for area source urban applications that involve reactive pollutants, but they require much more extensive input databases and resources and therefore are not as widely applied. Physical modeling involves the use of wind tunnels or other fluid modeling facilities. This class of modeling is a complex process requiring a high level of technical expertise, as well as access to the necessary facilities. Physical modeling may be useful for complex flow situations, such as building, terrain or stack downwash conditions, plume impact on elevated terrain diffusion in an urban environment, or diffusion in complex terrain. The dispersion models are categorized by two levels of sophistication: (1) Screening models, which provide conservative estimates of air quality impacts, and (2) Refined models, which provide a more detailed treatment of physical and chemical processes, but require more detailed and precise data for input in addition to higher computational costs.

Recommended air quality models are also divided into "preferred" and "alternative" model by the U.S. EPA. Preferred are models that EPA has either found better to perform than others in a given category, or has been chosen on factors such as faster use, public familiarity, and cost or resource requirements. As long as the preferred models are applied as indicated by the U.S. EPA they can be used without a formal demonstration of applicability. Alternative models can be utilized when (1) an alternative model can be shown to produce concentration estimates equivalent to estimates obtained from a preferred model use (2) the alternative model performs better for the specific application than the preferred model based on a statistical performance evaluation; (3) a refined model is needed to satisfy regulatory requirements but, no preferred model for the specific application exists.

Two common models used by the U.S. EPA are the Assessment population Exposure Model (ASPEN) and the Industrial Source Complex (ISC) Model. These two models are frequently used in the permitting process and for environmental health impacts, because they can indicate how existing and additional pollutant sources will affect the ambient air concentrations and potentially the exposed populations' health risk.

Assessment Population Exposure Model (ASPEN). The Assessment Population Exposure Model calculates ambient air levels based on meteorology, chemistry, and rates which air toxics are emitted into the atmosphere. Currently ASPEN's ambient concentration outputs are then used in conjunction with the Hazardous Air Pollutant Exposure Model (HAPEM4), as a screening tool to examine national exposure levels of specific toxic air pollutants. Estimated exposures can then be combined with quantitative health impact information to estimate population health risk estimates (U.S. EPA, 2000).

The ASPEN and ISC are two commonly used models that can be used to estimate ambient air concentrations. Estimated ambient concentrations outputs from these models can also be utilized to calculate human exposure and population health risk.

Industrial Source Complex Model (ISC). The Industrial Source Complex Model is a more specific and precise tool than the HEM. It uses local data and predicts pollutant levels at specific locations. The ISC is a steady-state Gaussian plume model that can be used to estimate air pollutant concentrations from a wide variety of sources associated with an industrial source complex (Zannetti, 1990). Both models, however, are simply tools to help scientists make evaluations of air pollution dispersion. The accuracy of the models is limited by the inherent problems of trying to simplify complex and interrelated factors that affect the transport and dispersion of air pollution.

In conclusion, meteorology plays an important role in the dispersion and transport of air pollution. It is inherently important to study its role within the strategies to control air pollution control and as part of air pollution dispersion modeling studies. As emissions released from one region continue to affect the population and ecosystems of another, air pollution dispersion modelers must attempt to understand the complex effects of meteorology upon the transport and dispersion of air pollutants.

NAME ____________________________________ DATE ________________ SCORE __________

CHAPTER 3 TRANSPORT AND DISPERSION OF AIR POLLUTION

Multiple Choice

Directions: Read each question and choose the best answer. Write the letter of your answer in the space provided.

1. As wind speed increases, the volume of air dispersed from a pollutant source over a specified period of time

a. increases.
b. decreases.
c. results in superadiabatic conditions.
d. results in isothermal conditions.
e. remains unchanged. **1.** _______

2. The three dimensional movement of the wind created by an uneven earth surface is called wind

a. Speed
b. Direction
c. Turbulence
d. Circulation
e. Mixing **2.** _______

3. Which topographical feature stores the most heat?

a. Lakes
b. Cultivated Fields
c. Mountains
d. Valleys
e. Draws **3.** _______

4. A __________________ occurs in stable atmospheric conditions; is generally produced on clear nights with little or light wind; and may spread horizontally but has little vertical air mixing.

a. Looping plume
b. Coning plume
c. Fanning plume
d. Lofting plume
e. Fumigating plume **4.** _______

5. A ______________________________ occurs in unstable atmospheric conditions; is generally produced on clear sunny days with light winds; and can draw pollution to ground level near the pollutant source.

a. Looping plume
b. Coning plume
c. Fanning plume
d. Lofting plume
e. Fumigating plume

5. ________

Matching

Directions: *Match the figure with the term that best defines the plume type and record the answer in the space provided.*

Environmental Effects of Air Pollution

_______ **6.** Looping plume

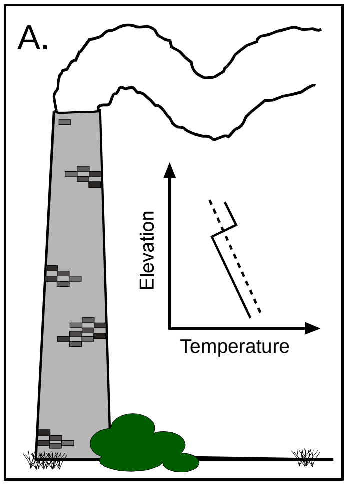
_______ **7.** Coning plume

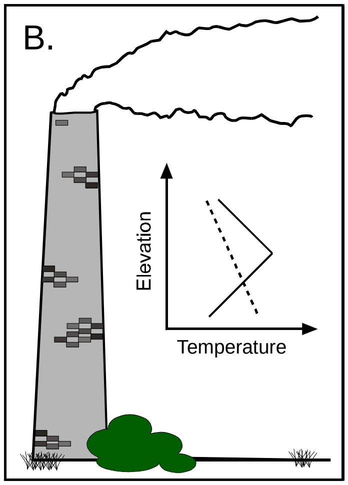
_______ **8.** Fanning plume

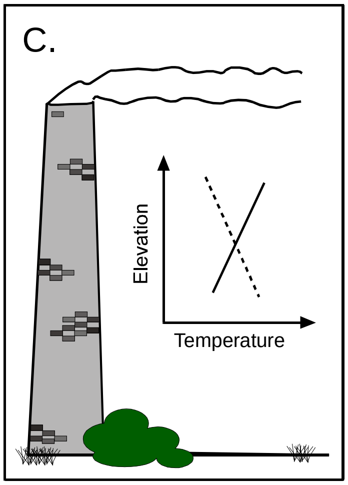
_______ **9.** Lofting plume

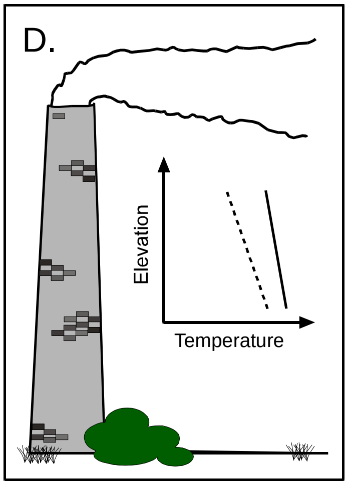
_______ **10.** Fumigating plume

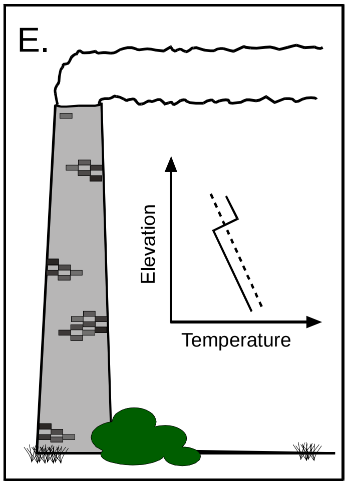
_______ **11.** Trapping plume

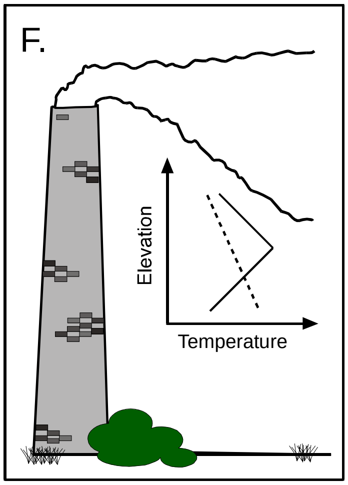






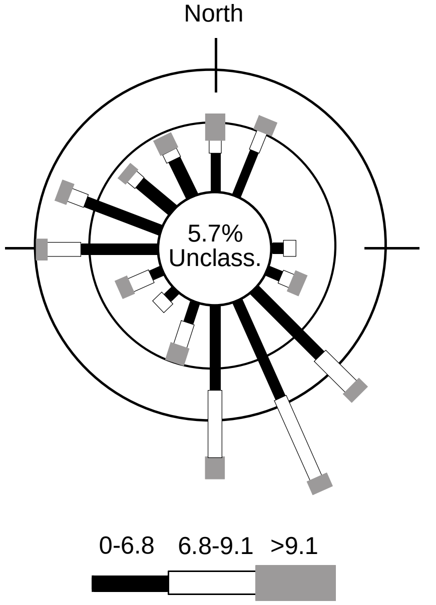




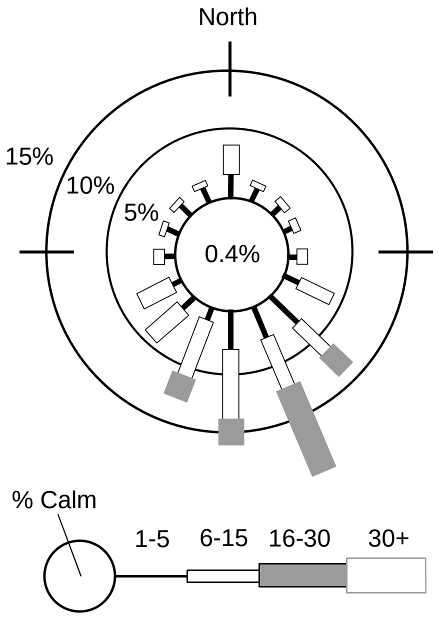


Wind Rose Interpretation

Directions: *Review the wind and pollution roses shown below. Answer each question using only the data obtained from each rose.*



Carbon Monoxide Concentration (mg/m$_3$)



Wind Speed and Direction (m/sec)

12. During the reporting period, winds blew most frequently to the ________________________.

13. List the wind directions that recorded wind speeds of at least 16 m/sec:

______________________________ ______________________________

______________________________ ______________________________

14. Carbon monoxide (CO) was most frequently observed in which direction?___________________

Least frequently? _______________

15. Which direction recorded the heaviest concentration of carbon monoxide (CO) pollution?

Direction: _________________________ Why? ______________________________________

____

____

____

16. Describe the relationship between wind speed and direction and pollutant concentration.

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	A	3-4
2.	C	3-6
3.	A	3-11, 3-6
4.	C	3-8
5.	A	3-8
6.	A	3-8 → 3-10
7.	D	
8.	C	
9.	B	
10.	F	
11.	E	

CHAPTER 4

Indoor Air Pollution

Lesson Goal

Demonstrate an understanding of the reasons for concern about the quality of indoor air, the changing approaches and elements to evaluating the quality of indoor air, and the benefits of an effective indoor air quality program by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Explain why indoor air pollution is a significant health risk.
2. Identify the major indoor air pollutants and their sources.
3. Define “Sick Building Syndrome” and its causes.
4. List the three major solutions to control or abate indoor air pollution.
5. Describe whose job is it to control indoor air pollution and the role of the U.S. EPA.

Recommended Reading: USEPA, *The Inside Story: A Guide to Indoor Air Quality*, EPA Document #402-K-93-007, April 1995.

Godish, Thad, “Indoor Air Pollution,” Air *Quality* (3rd ed.), New York: Lewis, 1997, pp. 341-382.

References

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Molina, C., C. Pickering, D. Valbjorn, and M. Debortoli, *Sick Building Syndrome: A Practical Guide*, Luxembourg: Joint Research Centre for the Environment, 1989, pp. 1-36.

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U.S. EPA, *A Citizen’s Guide to Radon, 3rd Edition*, EPA Document No. EPA-402-K-92-001, September 1992a.

U.S. EPA, *Targeting Indoor Air Pollutants: EPA’s Approach and Progress*, EPA Document No. 400R 92-012, 1993.

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U.S. EPA, *The Respiratory Effects of Passive Smoking: Lung Cancer and Other Disorders*, EPA Document No. EPA/600/6-90/006F, 1992b.

Woods, J.E., “Cost Avoidance and Productivity in Owning and Operating Buildings,” *Occup. Med. State Art Review*, Oct-Dec, 1989, pp. 753-769.

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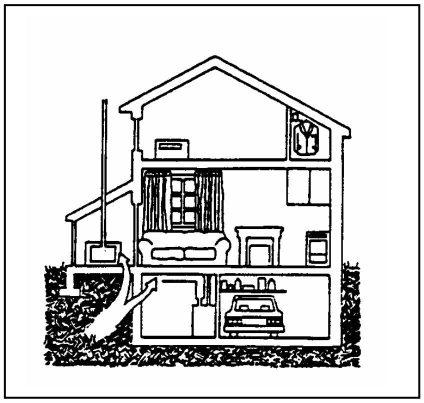
Indoor Air Pollution

Exposure to some pollutants may be two to five times higher indoors than outdoors.

While air pollution and its effect on human health and the environment continues to be a matter of increasing public concern, our interest and understanding of the problem of poor air quality has taken centuries to develop. As early as 1500 B.C., the Egyptians understood that inhaling silicate dust while cutting stone resulted in respiratory disease. In Ancient Greece, Hippocrates (460-314 B.C.) documented the adverse health effects produced by the air in mines. During the centuries preceding the Renaissance, urbanization lead to the widespread burning of coal and other fossil fuels, which soon became feared as a source of illness and death (Brooks and Davis, 1992).



As the emphasis on ambient air quality increased, a new awareness emerged about the potential health effects of indoor air pollution as well. In fact, it has been estimated that exposure to some pollutants may be two to five times higher indoors than outdoors. Although much of the documented evidence remains largely anecdotal, the science and technology of indoor air pollution control will continue to be developed and refined as scientific research continues.

The purpose of this chapter is to introduce many of the causes and solutions to indoor air pollution. Special emphasis will be placed upon what is known about air contaminants in buildings and the link between the causes of indoor air pollution and the resulting human health effects.

Indoor Air Pollution: Sources, Effects and Controls

Indoor temperature, humidity, lighting, and noise significantly magnify the harmful effects of indoor pollution.

Chemical and biological agents released in an enclosed environment create indoor air pollution. At present, more than 900 compounds have been identified as potential sources of indoor air pollution and the list continues to grow (Brooks and Davis, 1992). The adverse health effects of these substances are magnified in a closed, indoor environment. Added to pollutant-specific characteristics such as dose, rate, and concentration are environmental factors such as temperature, humidity, lighting, and noise that can intensify pollutant effects on human health and the environment (Molina, et al., 1989). Although outside air may contain a myriad of worrisome contaminants that frequently enter buildings through ventilation intakes, managers of ventilation systems must also contend with many sources of indoor air pollution as well.

The remainder of this section will explain the sources, effects and methods to reduce exposure to the following major indoor air contaminants: biological contaminants, radon, environmental tobacco smoke, carbon monoxide, nitrogen dioxide, particles, asbestos, formaldehyde, pesticides, organic chemicals, and lead.

Biological Contaminants

Biological contaminants include bacteria, molds, mildew, viruses, animal dander and cat saliva, house dust, mites, cockroaches, and pollen. There are many sources of these pollutants. Pollens originate from plants; viruses are transmitted by people and animals; bacteria are carried by people, animals, soil and plant debris; and household pets are sources of saliva and animal dander. The protein in urine from rats and mice is a potent allergen. When it dries, it can become airborne. Contaminated central air handling systems can become breeding grounds for mold, mildew, and other sources of biological contaminants and can then distribute these contaminants throughout the home.

By controlling the relative humidity level in a home, the growth of some sources of biologicals can be minimized. A relative humidity of 30-50 percent is generally recommended for homes. Standing water, water-damaged materials, or wet surfaces also serve as a breeding ground for molds, mildews, bacteria, and insects. House dust mites, the source of one of the most powerful biological allergens, grow in damp, warm environments.

Health Effects of Biological Contaminants. Some biological contaminants trigger allergic reactions, including hypersensitivity pneumonitis, allergic rhinitis, and some types of asthma. Infectious illnesses, such as influenza, measles, and chicken pox are transmitted through the air. Molds and mildews release disease-causing toxins. Symptoms of health problems caused by biological pollutants include sneezing, watery eyes, coughing, dizziness, shortness of breath, lethargy, fever, and digestive problems.

Ways to Reduce Exposure. Some good ways to reduce exposure to indoor contaminants is to install and use fans vented outdoors in kitchens and bathrooms. Also vent clothes dryers to the outdoors. Be sure to use clean mist and ultrasonic humidifiers in accordance with manufacturer's instructions and refill with clean water daily. Empty water trays in air conditioners, dehumidifiers, and refrigerators frequently. Clean and dry or remove water-damaged carpets. Use basements as living areas only if they are leak-proof and have adequate ventilation, and finally, use dehumidifiers, if necessary, to maintain indoor humidity between 30-50 percent.

Radon (Rn)

Radon is a naturally forming radioactive gas produced when uranium decays. As uranium breaks down, it releases radon that diffuses into the air and water supply for human consumption. Radon and other radium decay products that are breathed into the lungs will continue to release deadly radiation as they continue to deteriorate. As radon concentrations build in the human body, elevated levels may result in lung cancer. The U.S. EPA has estimated that radon is responsible for 14,000 to 30,000 deaths each year (U.S. EPA, 1992).

Radon is responsible for 14,000 to 30,000 deaths each year.

The most common source of indoor radon is uranium in the soil or rock on which homes are built. As uranium naturally breaks down, it releases radon gas that is a colorless, odorless, radioactive substance. Radon gas enters homes through dirt floors, cracks in concrete walls and floors, floor drains, and sumps. When radon becomes trapped in buildings and concentrations build up indoors, exposure to radon becomes a concern. Any home can have a radon problem, whether it be new or old homes, well sealed or drafty, and homes with or without basements. Sometimes radon enters the home through well water, and in a small number of homes, the building materials can give off radon, too.

Health Effects of Radon. The predominant health effect associated with exposure to elevated levels of radon is lung cancer. Research suggests that swallowing water with high radon levels may pose risks, too, although these are believed to be much lower than those from breathing air contaminated with radon. Major health organizations, like the Centers for Disease Control and Prevention, the American Lung Association (ALA), and the American Medical Association, agree with estimates that radon causes thousands of preventable lung cancer deaths each year. Although EPA estimates that radon causes about 14,000 deaths per year in the United States—if you smoke and your home has high radon levels, your risk of lung cancer is even higher.

Ways to Reduce Exposure. The average indoor radon level is estimated to be about 1.3 picocuries per liter (pCi/L), while about 0.4 pCi/L of radon is normally found in the outside air. The U.S. Congress set a long-term goal that indoor radon levels be no more than outdoor levels. While this goal is not yet technologically achievable in all cases, most homes today can be reduced to 2 pCi/L or below. Fix your home if your radon level is 4 pCi/L or higher. Radon levels less than 4 pCi/L still pose a risk, and in many cases may be reduced.

Proper insulation, caulking, and sealing can significantly, but not entirely eliminate Radon exposure. In most cases, sub-slab ventilation systems are necessary.

A variety of methods can be used to reduce radon in homes. Sealing cracks and other openings in the foundation is a basic part of most approaches to radon reduction. EPA does not recommend the use of sealants alone to limit radon entry. Sealing alone has not been shown to lower radon levels significantly or consistently. In most cases, a system with a vent pipe(s) and fan(s) is used to reduce radon. These "sub-slab depressurization" systems do not require major changes to your home.

Similar systems can also be installed in homes with a crawl space. These systems prevent radon gas from entering the home from below the concrete floor and from outside the foundation. Radon mitigation contractors may use other methods that may also work in your home. The right system depends on the design of your home and other factors. Reduce your risk of lung cancer by lowering your radon level.

Although much has been done to prevent radon poisoning by businesses and homeowners, governmental regulation has not kept pace with private efforts. There are many reasons why this is true, but chief among them is that laws and regulations have not been well defined because indoor air pollution and the human health effects of radon have only become a public issue since the Clean Air Act Amendments of 1990. In addition, public education of the hazards associated with radon has only begun in recent years. But, perhaps most importantly, there continues to be a lingering scientific debate over the magnitude of the health problems directly caused by this substance.

Environmental Tobacco Smoke (ETS)

Environmental tobacco smoke (ETS) is the mixture of smoke that comes from the burning end of a cigarette, pipe, or cigar, and smoke exhaled by the smoker. It is a complex mixture of over 4,000 compounds, more than 40 of which are known to cause cancer in humans or animals and many of which are strong irritants. ETS is often referred to as "secondhand smoke" and exposure to ETS is often called "passive smoking."

Over 50 million smokers release secondary smoke from 467,000 tons of tobacco smoked annually.

In 1992, EPA completed a major assessment of the respiratory health risks of ETS. The report concludes that exposure to ETS is responsible for approximately 3,000 lung cancer deaths each year in nonsmoking adults and impairs the respiratory health of hundreds of thousands of children (U.S. EPA, 1992b).

Stoves, Heaters, Fireplaces, and Chimneys

In addition to environmental tobacco smoke, other sources of combustion products are unvented kerosene and gas space heaters, woodstoves, fireplaces, and gas stoves. The major pollutants released are carbon monoxide, nitrogen dioxide, and particles. Unvented kerosene heaters may also generate acid aerosols.

Combustion gases and particles also come from chimneys and flues that are improperly installed or maintained and cracked furnace heat exchangers. Pollutants from fireplaces and woodstoves with no dedicated outdoor air supply can be "back-drafted" from the chimney into the living space, particularly in weatherized homes.

Ways to Reduce Exposure. Take special precautions when operating fuel burning, unvented space heaters. A persistent yellow-tipped flame is generally an indicator of maladjustment and increased pollutant emissions. Install and use exhaust fans over gas cooking stoves and ranges and keep the burners properly adjusted. Have central air handling systems, including furnaces, flues, and chimneys, inspected annually and promptly repaired.

Asbestos

Asbestos is a mineral fiber that has been commonly used in a variety of building construction materials for insulation and as a fire-retardant. EPA and CPSC have banned several asbestos products. Manufacturers have also voluntarily limited uses of asbestos. Today, asbestos is most commonly found in older homes, in pipe and furnace insulation materials, asbestos shingles, millboard, textured paints and other coating materials, and floor tiles.

Elevated concentrations of airborne asbestos can occur after asbestos-containing materials are disturbed by cutting, sanding or other remodeling activities. Improper attempts to remove these materials can release asbestos fibers into the air in homes, increasing asbestos levels and endangering people living in those homes.

Health Effects of Asbestos. The most dangerous asbestos fibers are too small to be visible. After they are inhaled, they can remain and accumulate in the lungs. Asbestos can cause lung cancer, mesothelioma (a cancer of the chest and abdominal linings), and asbestosis (irreversible lung scarring that can be fatal). Unfortunately, symptoms of these diseases do not show up until many years after exposure began.

Mesothelioma, a rare form of cancer caused by asbestos exposure, has a mortality rate of 100%. Asbestosis is also a debilitating lung disease.

Ways to Reduce Exposure. Usually it is best to leave asbestos material that is in good condition alone. Generally, material in good condition will not release asbestos fiber. There is no danger unless fibers are released and inhaled into the lungs. Do not cut, rip, or sand asbestos-containing materials.

Pesticides

According to a recent survey, 75 percent of U.S. households used at least one pesticide product indoors during the past year. Products used most often are insecticides and disinfectants. Another study suggests that 80 percent of most people's exposure to pesticides occurs indoors and that measurable levels of up to a dozen pesticides have been found in the air inside homes. The amount of pesticides found in homes appears to be greater than can be explained by recent pesticide use in those households; other possible sources include contaminated soil or dust that floats or is brought in from outside, stored pesticide containers, and household surfaces that collect and then release the pesticides. Pesticides used in and around the home include products to control insects (insecticides), termites (termiticides), rodents (rodenticides), fungi (fungicides), and microbes (disinfectants). They are sold as sprays, liquids, sticks, powders, crystals, balls, and foggers.

Health Effects of Pesticides. Both the active and inert ingredients in pesticides can be organic compounds; therefore, both could add to the levels of airborne organics inside homes. Exposure to high levels of cyclodiene pesticides, commonly associated with misapplication, has produced various symptoms, including headaches, dizziness, muscle twitching, weakness, tingling sensations, and nausea. In addition, EPA is concerned that cyclodienes

EPA estimates that roughly 2.5 million households experienced acute pesticide-related health effects between 1966 and 1977.

might cause long-term damage to the liver and the central nervous system, as well as an increased risk of cancer.

Ways to Reduce Exposure. Read the label and follow the directions. (It is illegal to use any pesticide in any manner inconsistent with the directions on its label.) Ventilate the area well after pesticide use. Use non-chemical methods of pest control when possible, and dispose of unwanted pesticides safely. Finally, keep exposure to moth repellents to a minimum.

Organic Chemicals

Organic chemicals are widely used as ingredients in household products. Paints, varnishes, and wax all contain organic solvents, as do many cleaning, disinfecting, cosmetic, degreasing, and hobby products. Fuels are made up of organic chemicals. All of these products can release organic compounds while you are using them, and, to some degree, when they are stored.

EPA's Total Exposure Assessment Methodology (TEAM) studies found levels of about a dozen common organic pollutants to be 2 to 5 times higher inside homes than outside, regardless of whether the homes were located in rural or highly industrial areas. Additional TEAM studies indicate that while people are using products containing organic chemicals, they can expose themselves and others to very high pollutant levels, and elevated concentrations can persist in the air long after the activity is completed.

Health Effects of Organic Chemicals. The ability of organic chemicals to cause health effects varies greatly, from those that are highly toxic, to those with no known health effect. As with other pollutants, the extent and nature of the health effect will depend on many factors including level of exposure and length of time exposed. Eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment are among the immediate symptoms that some people have experienced soon after exposure to some organics. At present, not much is known about what health effects occur from the levels of organics usually found in homes. Many organic compounds are known to cause cancer in animals; some are suspected of causing, or are known to cause, cancer in humans.

Ways to Reduce Exposure. Follow label instructions carefully. Potentially hazardous products often have warnings aimed at reducing exposure of the user. Throw away partially full containers of old or unneeded chemicals safely.

Formaldehyde

Formaldehyde is an important chemical used widely by industry to manufacture building materials and numerous household products. It is also a by-product of combustion and certain other natural processes. Thus, it may be present in substantial concentrations both indoors and outdoors.

Sources of formaldehyde in the home include building materials, smoking, household products, and the use of unvented, fuel-burning appliances, like gas stoves or kerosene space heaters. Formaldehyde, by itself or in combination with other chemicals, serves a number of purposes in manufactured products. For example, it is used to add permanent-press qualities to clothing and draperies, serves as a component of glues and adhesives, and is used as a preservative in some paints and coating products.

In homes, the most significant sources of formaldehyde are likely to be pressed wood products made using adhesives that contain urea-formaldehyde (UF) resins. Pressed wood products made for indoor use include: particleboard (used as subflooring and shelving and in cabinetry and furniture); hardwood plywood paneling (used for decorative wall covering and used in cabinets and furniture); and medium density fiberboard (used for drawer fronts, cabinets, and furniture tops). Medium density fiberboard contains a higher resin-to-wood ratio than any other UF pressed wood product and is generally recognized as being the highest formaldehyde-emitting pressed wood product.

HCHO may be commonly found in construction materials such as particleboard, fiberboard, and hardwood plywood.

The rate at which products like pressed wood or textiles release formaldehyde can change. Formaldehyde emissions will generally decrease as products age. When the products are new, high indoor temperatures or humidity can cause increased release of formaldehyde from these products.

During the 1970s, many homeowners had urea-formaldehyde foam insulation (UFFI) installed in the wall cavities of their homes as an energy conservation measure. However, many of these homes were found to have relatively high indoor concentrations of formaldehyde soon after the UFFI installation. Few homes are now being insulated with this product. Studies show that formaldehyde emissions from UFFI decline with time; therefore, homes in which UFFI was installed many years ago are unlikely to have high levels of formaldehyde now.

Acute health effects of HCHO exposure include eye irritation, runny nose, sinus congestion, cough, rashes, and menstrual irregularities.

Health Effects of Formaldehyde. Formaldehyde is a colorless, pungent-smelling gas that can cause watery eyes, a burning sensation in the eyes and throat, nausea, and difficulty in breathing in some humans exposed at elevated levels (above 0.1 parts per million). High concentrations may trigger asthma attacks in people with asthma. There is some evidence that people can develop sensitivity to formaldehyde, but it has also been shown to cause cancer in animals and may cause cancer in humans.

Ways to Reduce Exposure. Ask about the formaldehyde content of pressed wood products, including building materials, cabinetry, and furniture before you purchase them. Some studies suggest that coating pressed wood products with polyurethane may reduce formaldehyde emissions for some period of time. The rate at which formaldehyde is released is accelerated by heat and may also depend somewhat on the humidity level. Therefore, the use of dehumidifiers and air conditioning to control humidity and to maintain a moderate temperature can help reduce formaldehyde emissions. Increasing the rate of ventilation in your home will also help in reducing formaldehyde levels.

Lead (Pb)

Lead has long been recognized as a harmful environmental pollutant. In late 1991, the Secretary of the Department of Health and Human Services called lead the "number one environmental threat to the health of children in the United States." There are many ways in which humans are exposed to lead: through air, drinking water, food, contaminated soil, deteriorating paint, and dust. Airborne lead enters the body when an individual breathes or swallows lead particles or dust once it has settled. Before it was known how harmful lead could be, it was used in paint, gasoline, water pipes, and many other products.

Old lead-based paint is the most significant source of lead exposure in the U.S. today. Harmful exposures to lead can be created when lead-based paint is improperly removed from surfaces by dry scraping, sanding, or open-flame burning. High concentrations of airborne lead particles in homes can also result from lead dust from outdoor sources, including contaminated soil tracked inside, and use of lead in certain indoor activities such as soldering and stained-glass making.

Health Effects of Lead: Lead affects practically all systems within the body. At high levels it can cause convulsions, coma, and even death. Lower levels of lead can adversely affect the brain, central nervous system, blood cells, and kidneys.

The effects of lead exposure on fetuses and young children can be severe. They include delays in physical and mental development, lower IQ levels, shortened attention spans, and increased behavioral problems. Fetuses, infants, and children are more vulnerable to lead exposure than adults since lead is more easily absorbed into growing bodies, and the tissues of small children are more sensitive to the damaging effects of lead. Children may have higher exposures since they are more likely to get lead dust on their hands and then put their fingers or other lead-contaminated objects into their mouths. Therefore, children are a significant risk group that should be tested for lead exposure.

Ways to Reduce Exposure. Some ways to reduce the risk of exposure of lead is to avoid the use of lead-based paints. Most homes built before 1960 contain heavily leaded paint. Some homes built as recently as 1978 may also contain significant quantities of lead. This paint could be on window frames, walls, the outside of homes, or other surfaces. Leave lead-based paint undisturbed if it is in good condition.

Although the incidence of lead poisoning continues to decline, estimates indicate that human accumulation of lead is 300 to 500 times greater today than has been found in our preindustrial ancestors.

Do not bring lead dust into the home; change clothes at work or wash contaminated clothing immediately. If you work in construction, demolition, painting, with batteries, in a radiator repair shop or lead factory, or your hobby involves lead, you may unknowingly bring lead into your home on your hands or clothes. You may also bring in lead from the soil around your home. Soil very close to homes may be contaminated from lead paint on the outside of the building. Soil by roads and highways may be contaminated from years of exhaust fumes from cars and trucks that used leaded gasoline.

Find out about lead in drinking water. Most well and city water does not contain lead, but water transported from household plumbing that is made with lead materials can easily contaminate the water quality. The only sure way to know if there is lead in drinking water is to have it tested.

Eat right. A child who gets enough iron and calcium will absorb less lead. Foods rich in iron include eggs, red meats, and beans. Dairy products are also high in calcium, but do not store food or liquid in lead crystal glassware or imported or old pottery.

Indoor air quality problems are not limited to homes. In fact, many office buildings have significant air pollution sources. Some of these buildings may be inadequately ventilated. For example, mechanical ventilation systems may not be designed or operated to provide adequate amounts of outdoor air. In addition, people generally have less control over the indoor environment in their offices than they do in their homes. As a result, there has been increased attention paid to the incidence of reported health problems.

SICK BUILDING SYNDROME (SBS)

Sick Building Syndrome (SBS) is a term used to refer to a variety of unrelated symptoms or health effects that are reported by at least twenty percent of a building’s occupants (Yocum and McCarthy, 1991). SBS is unusual because it cannot be easily traced to a specific pollutant or source, yet the symptoms seem to diminish when the occupant leaves the building. While the sources of SBS are elusive, the symptoms of building-related illness are not. Symptoms of SBS include irritation of the eyes, nose, and throat; skin dryness and irritation; headaches and nausea; and runny or blocked nose (Skov, 1992).

Illnesses attributed to SBS represent a wide range of complaints that could be characterized from minor to extremely lethal. Pontiac fever, for example, is spread by a Legionella bacterium that is a highly infectious nonpnemonic illness that results in a ninety-five percent infection rate among those exposed. Legionnaire's disease, well publicized during the 1980's, is a life threatening bronchopneumonia spread by the Legionella pneumonphilia bacteria. Indoor molds, bacteria, dust, and organic chemicals can result in various forms of pneumonitis and bronchitis. For example, humidifier fever is a general malaise, cough, and dyspnea that are spread indoors by fungi, protozoa, endotoxins, and arthropods (Brooks and Davis, 1992).

Pontiac fever, Legionnaire's disease, and Humidifier fever are all illnesses frequently attributed to Sick Building Syndrome.

While there may be no clear, scientific consensus identifying the cause of many of these building-related illnesses, it is clear that indoor air quality problems are more prevalent and severe than once thought. Preliminary estimates suggest that building-related illnesses result in direct medical costs of over $1 billion each year (Molina, et al., 1989). Indoor air quality can also destroy expensive instruments and equipment resulting in unnecessary cleaning, recalibration, or repair costs. However, perhaps the most significant cost of SBS is to human productivity. Illnesses resulting from indoor air pollution account for $4.7 billion annually in lost wages and reduced industrial productivity (Woods, 1989). Unfortunately, this estimate does not include the full effect of reduced work efficiency.

Building-related illness accounts for over $1 billion in direct medical costs and $4.7 billion in lost wages and productivity each year.

The SBS Problem. Three major reasons exist for poor indoor air quality in office buildings. These include the presence of indoor air pollution sources; poorly designed, maintained, or operated ventilation systems; and uses of the building that were unanticipated or poorly planned when the building was designed or renovated.

As with homes, the most important factor influencing indoor air quality is the presence of pollutant sources. Commonly found office pollutants and their sources include environmental tobacco smoke; asbestos from insulating and fire-retardant building supplies; formaldehyde from pressed wood products; other organics from building materials, carpet, and other office furnishings, cleaning materials and activities, restroom air fresheners, paints, adhesives, copying machines, and photography and print shops;

biological contaminants from dirty ventilation systems or water-damaged walls, ceilings, and carpets; and pesticides from pest management practices.

However, the leading cause of Sick Building Syndrome is the use of poorly designed, maintained, or operated ventilation systems. Mechanical ventilation systems in large buildings are designed and operated not only to heat and cool the air, but also to draw in and circulate outdoor air. If they are poorly designed, improperly operated, or insufficiently maintained, ventilation systems can become a major source of indoor air pollution.

For example, problems arise when, in an effort to save energy, ventilation systems are not used to bring in adequate amounts of outdoor air. Inadequate ventilation also occurs if the air supply and return vents within each room are blocked or placed in such a way that outdoor air does not actually reach the breathing zone of building occupants. Improperly located outdoor air intake vents can also bring in air contaminated with automobile and truck exhaust, boiler emissions, fumes from dumpsters, or air vented from restrooms. Finally, ventilation systems can be a source of indoor air pollution by spreading biological contaminants that have multiplied in cooling towers, humidifiers, dehumidifiers, air conditioners, or the inside surfaces of ventilation duct work.

Indoor air pollutants can be circulated from portions of the building used for specialized purposes, such as restaurants, print shops, and dry-cleaning stores, into offices in the same building. Carbon monoxide and other components of automobile exhaust also can be drawn from underground parking garages through stairwells and elevator shafts into office spaces.

Finally, buildings originally designed for one purpose may be converted later for office use. If not properly modified during building renovations, the room partitions and ventilation system can contribute to indoor air quality problems by restricting airflow or by providing an inadequate supply of outdoor air.

Indoor Air Pollution: Solutions

Recurring adverse health effects that have been properly documented can be a useful indicator of an indoor air quality problem. While pollutants identified in the indoor air are responsible for many harmful effects, there remains considerable debate and uncertainty about what concentrations or periods of exposure are necessary to produce specific health-related illnesses. Although the science is still developing, the need to measure indoor air pollutant levels remains vital. Generally, three strategies have been adopted to combat indoor air pollution.

Source Control. The most effective way to improve indoor air quality is to identify and eliminate potential sources of pollution or significantly reduce their impact by controlling their emissions. Some pollutants, such as asbestos, can be sealed or enclosed while others, such as gas stoves, must be adjusted to control the amount of pollutants released into the atmosphere. In many cases, source control is a more cost-effective way to protect indoor air quality because it seldom requires costly modifications or additional equipment (U.S. EPA, 1995).

Source control, proper ventilation, and the use of air cleaners are three strategies to combat indoor air pollution.

Ventilation. One way to lower the concentration of indoor air pollution is to increase the amount of outdoor air vented indoors. Most heating and cooling systems are not designed to mechanically vent fresh air indoors; however, advanced designs of new homes and businesses are beginning to feature energy-efficient ventilators that provide fresh air exchange. Ventilation is the most important method for controlling indoor air quality, particularly in those environments that have high levels of pollutant exposure such as paints, solvents, kerosene heat, welding, cooking, or soldering. Under these conditions it is imperative to open windows, operate attic fans, and use vent controls to increase fresh air exchange (U.S. EPA, 1995).

Air Cleaners. Air cleaners of various sizes and types have begun to appear on the market in response to concerns over Environmental Tobacco Smoke (ETS). While air cleaners do little to filter gaseous pollutants, they can be quite effective at particle removal. In addition, research suggests that common houseplants can effectively reduce harmful levels of chemicals. Although plants can have a positive impact on indoor air quality, they can also serve as a source of indoor pollen and mold spores. In addition, there is currently no evidence to suggest that plants can filter significant quantities of ETS (U.S. EPA, 1995).

Studies conducted by agencies such as the U.S. EPA have resulted in a greater recognition of the effects of indoor air pollution. The presence of particulate matter and organic /inorganic gases indoors requires further monitoring of indoor air quality to help define concentrations of pollutants. Continued attention to indoor air quality will be necessary to control excess exposure to indoor air pollutants.

EPA APPROACH AND PROGRESS

Indoor air pollution is such an important issue because people spend as much as 90% of their time indoors.

Most people are aware that outdoor air pollution can damage their health, but they may not know that indoor air pollution can also have significant harmful effects. U.S. EPA studies of human exposure to air pollutants indicate that indoor levels of many pollutants may be 2 to 5 times higher, and occasionally more than 100 times higher than outdoor levels. These levels of indoor air pollutants are of particular concern because it is estimated that most people spend as much as 90% of their time indoors.

Over the last several decades, our exposure to indoor air pollutants is believed to have increased due to a variety of factors: the construction of more tightly sealed buildings, reduced ventilation rates to save energy, the use of synthetic building materials and furnishings, and the use of chemically formulated personal care products, pesticides and household cleaners.

EPA ranks indoor air pollution among the top five environmental risks to public health.

In recent years, comparative risk studies performed by EPA and its Science Advisory Board have consistently ranked indoor air pollution among the top five environmental risks to public health. EPA, in close cooperation with other Federal agencies and the private sector, has begun a concerted effort to better understand indoor air pollution and to reduce peoples' exposure to air pollutants in their offices, homes, schools and other indoor environments where people live, work and play.

EPA Indoor Air Program. Because of the potentially serious impact on the health of individuals who may experience indoor air quality problems—as well as the dollar costs to society if indoor air pollution is not addressed—EPA has developed a comprehensive program to better understand the indoor air pollution problem and to take decisive steps to reduce people's exposures to indoor air contaminants of all types.

Even in the absence of complete scientific understanding of indoor air pollution, prudent public policy dictates that reasonable efforts be undertaken to reduce people's exposure to potentially harmful levels of indoor air pollutants by using the resources available to the Federal government under current laws.

Pollution prevention—and efficient resolution of indoor air quality problems of all types—must become a routine aspect of the design, construction, maintenance, and operation of public and commercial buildings, homes, health and daycare facilities, educational institutions and other special use buildings. An effective research and development program must be conducted to achieve a more complete understanding of the factors affecting indoor air quality, exposure patterns, health effects, and control techniques for improving indoor air quality.

EPA is implementing this program using non-regulatory as well as regulatory tools available under a number of Federal laws to provide information and incentives for action to protect manufacturers, architects, engineers, builders, building owners and managers, and building occupants.

Other Federal Agencies. More than 20 Federal agencies have responsibilities associated with indoor air quality, either through their own statutory responsibilities or because they are major property managers. The activities of these agencies are coordinated through a variety of mechanisms, including an interagency Committee on Indoor Air Quality (CIAQ), which meets on a quarterly basis to exchange information on indoor air issues.

Five Federal agencies—EPA, the Consumer Product Safety Commission, the Department of Energy, the National Institute for Occupational Safety and Health, and the Occupational Safety and Health Administration—are CIAQ co-chair agencies. In addition, EPA works closely with other agencies on regulatory and information development efforts and jointly sponsors many of its guidance and public information documents with these other agencies to help ensure that Federal actions are well coordinated.

NAME ______________________________________ DATE _____________ SCORE __________

CHAPTER 4 INDOOR AIR POLLUTION

Multiple Choice

Directions: Read each question and choose the best answer. Write the letter of your answer in the space provided.

1. Indoor air pollution has become a matter of great concern because the average person spends _______ of their time indoors.

a. 90% (22 hrs./day)
b. 70% (17 hrs./day)
c. 50% (12 hrs./day)
d. 30% (7 hrs./day)
e. 10% (2 hrs./day) **1.** _______

2. A radioactive gas – found on the Periodic Table of Elements – that is a by-product of uranium decay and is found in nearly all soils is _______.

a. potassium (K)
b. plutonium (Pu)
c. radium (Ra)
d. uranium isotopes (U)
e. radon (Rn) **2.** _______

3. Each of the following are ways to control indoor air pollution **except** _______.

a. eliminate the source
b. install carbon monoxide (CO) detectors
c. modify the source
d. ventilate and dilute the air
e. filter the air **3.** _______

4. The most common method of controlling indoor air pollution today is to _______.

a. identify and eliminate the source
b. install carbon monoxide (CO) detectors
c. modify the source
d. ventilate and dilute the air
e. filter the air **4.** _______

5. The leading cause of “Sick Building” Syndrome is _______.

a. inadequate ventilation
b. poor maintenance
c. excess levels of radium
d. spread of biological contaminants
e. ingestion of respirable particles

5. _______

6. Sources of indoor organic chemicals may be which of the following _______.

a. paints, varnishes and solvents
b. cleaning, degreasing and hobby products
c. gasoline
d. all of the above
e. only a & c

6. _______

7. Biological contaminants include all of the following **except** _______.

a. bacteria
b. molds
c. animal dander
d. carbon monoxide
e. pollen

7. _______

8. Preliminary estimates suggest that building-related illnesses result in direct medical costs in excess of _______.

a. $ 1 million
b. $ 1 billion
c. $ 4.7 billion
d. $ 10 million
e. $ 10 billion

8. _______

9. Indoor levels of many pollutants may be_______ times higher indoors than outdoors.

a. 5
b. 10
c. 15
d. 20
e. 25

9. _______

10. Pontiac fever, Legionnaire’s disease, and Humidifier fever have all been found to be examples of _______.

a. “Sick Building” Syndrome
b. Asbestosis
c. Pulmonary edema
d. Mesothelioma
e. respiratory xyhemoglobin

10. _______

Matching

Directions: *Match each example with its source of indoor air pollution. Each source may be selected more than once.*

Selected Sources of Indoor Air Contaminants

_______ **11.** Insulation

_______ **12.** Glue

_______ **13.** Arachnid Excretia

_______ **14.** Tobacco Products

_______ **15.** Office Equipment

_______ **16.** Oil Furnace

_______ **17.** Interior Grade Plywood

_______ **18.** Kerosene Heaters

_______ **19.** House Dust

_______ **20.** Foam Insulation

_______ **21.** Siding

_______ **22.** Dry Cleaned Clothing

_______ **23.** Furniture

_______ **24.** Furniture Polish

a. Biological Contaminants

b. CO, SO_2, NO_2

c. Formaldehyde

d. Asbestos

e. Respirable Particulates

f. Organic chemicals

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	A	4-16
2.	E	4-5
3.	B	4-15
4.	A	4-15
5.	A	4-14
6.	D	4-9
7.	D	4-4
8.	B	4-14
9.	E	4-16
10.	A	4-14
11.	D	Entire Chapter
12.	F	
13.	A	
14.	B, E	
15.	E, F	
16.	B	
17.	C	
18.	B, E	
19.	A	
20.	C	
21.	D	
22.	F	
23.	C	
24.	F	

CHAPTER 5

The United States Clean Air Act

Lesson Goal

Demonstrate an understanding of the U.S. Clean Air Act and its programs by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Describe the NAAQS and SIP. State the responsibility of EPA when states fail to enforce their implementation plans.
2. Describe the New Source Review program.
3. Determine when a PSD, Nonattainment and a NSPS permit must be obtained.
4. Define; potential to emit, the bubble concept, offsets, and nonattainment classifications.
5. Define NSPS, BACT, and LAER.
6. Describe the new HAP program, MACT, and Residual Risk.
7. Detail the Enforcement Provisions of the CAA: Civil, Administrative, and Criminal.

Recommended Reading: Godish, Thad, "Indoor Air Pollution," *Air Quality*, 3rd Edition, New York: Lewis 1997, pp. 215-284.

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The United States Clean Air Act

What does the Clean Air Act (CAA) regulate? The CAA, in Section 302, defines “air pollution” as material that is emitted or otherwise enters the *ambient* air and causes negative health effects; or damages plants, property or animals; or causes an unreasonable interference with the enjoyment of life or property. The EPA defines ambient air as “that portion of the atmosphere external to buildings, to which the public has access.” Accordingly, the CAA regulates only pollution that enters the outside air. This includes emissions from stacks, chimneys, vents and any other functionally equivalent openings. These are called point source emissions, or area emissions depending on their size. The CAA also regulates mobile and fugitive emissions that are released directly into the atmosphere. What the CAA does not regulate is indoor air pollution, or air pollution confined to private property, such as occupationally exposed emissions.

Air pollution is any hazardous material that enters the ambient air that may cause damage to human health or the environment.

National Ambient Air Quality Standards

As required by the CAA, the EPA must publish "criteria documents" for pollutants that satisfy certain conditions specified in section 108(a). Under section 109, EPA must establish National Ambient Air Quality Standards (NAAQS) for every pollutant that has been designated a "criteria" pollutant. EPA has promulgated National Ambient Air Quality Standards for six criteria air pollutants: ozone, particulates (PM_{10} and $PM_{2.5}$), sulfur oxides, carbon monoxide, nitrogen dioxide and lead. The value of a standard depends largely upon the time period over which the measurement is averaged. For each pollutant, there is a reference method.

The Act requires that EPA review these standards every five years. EPA has not added a new pollutant to this list since lead in 1976. In 1979, EPA revised the old photochemical oxidant standard and restated it as an ozone standard, and four years later withdrew the old hydrocarbon standard. In 1987, EPA revised the particulates standard from total suspended particulate matter to particulate matter less than 10 microns (PM_{10}) standard. Later, in 1997, EPA revised the ozone standard and added the particulate matter less than 2.5 microns ($PM_{2.5}$) to the particulates standard. The federal appellate court remanded the 1997 revisions, but the United States Supreme Court upheld the standards. Nonetheless, several issues still remain before the Circuit Court of Appeals for Washington D.C.

Types of NAAQS:

- *Primary standard: "Health-based" standards used to protect human health and the environment.*
- *Secondary standard: Designed to protect general public welfare and prevention of damage to public property.*

There are two types of NAAQS specified in Section 109 of the CAA: primary and secondary. Primary NAAQS are set at a level which allows an "ample margin of safety" and are considered necessary to protect human health and the environment. These are *health-based* standards that do not allow costs or availability of control technology to be taken into consideration. This health-based standard must protect the most sensitive segments of the population, such as children, the elderly and asthmatics. Secondary NAAQS are aimed at the protection of public welfare and the prevention of damage to animals, plant life, and property. Both primary and secondary NAAQS specify the maximum concentrations of these pollutants that can be present in the ambient air. The present primary and secondary standards are the same for four of the six criteria pollutants. These standards are based on scientific and medical studies of pollutant effects.

Air Quality Control Regions

The CAA originally required EPA to divide the country into 247 air quality control regions based on common meteorological, industrial and topographical factors. These AQCRs no longer have much regulatory significance; however, the CAA also requires EPA to designate all areas of the country as Attainment, Nonattainment or Unclassifiable. These area designations are "pollution specific" (i.e., a region may be classified attainment for SO_2, but nonattainment for ozone and particulates). An area is classified as "attainment" for a specific criteria pollutant if the area meets the NAAQS. An area is classified as “nonattainment” for a specific criteria pollutant if the area does not meet the NAAQS. An “unclassifiable” area is an area that cannot be classified because there is a lack of information to determine whether the area meets the NAAQS.

As of 1990, nonattainment areas have different classifications for three criteria pollutants. Ozone nonattainment areas are divided into five classifications: Marginal, Moderate, Serious, Severe, or Extreme. Nonattainment areas for carbon monoxide and particulates are divided only into two classifications: Moderate or Serious. Classifications have different substantive requirements for each criteria pollutant. These requirements can be cumulative or unique. Requirements increase for an area as the severity of the classification increases (i.e., deadlines for attainment, offset ratios, definition of "major source"). Cumulative requirements are additive (i.e., a Serious classification has to satisfy all the requirements of its class and all the lower classes, such as Moderate & Marginal).

Nonattainment classifications for ozone *and* carbon monoxide *can be cumulative or unique. Cumulative requirements are additive while unique requirements are a fixed standard.*

Nonattainment areas are "classified" based on their severity of nonattainment. For example, ozone and carbon monoxide measure severity by calculation of a "design value.” Their "design values" are presently calculated the same way: the fourth highest ambient air concentration over a 3-year period. The design value for ozone, under the 8-hour ozone standard, was the average of the fourth highest exceedance of the NAAQS measured in each of the three years at the highest reading site in the area.

Particulates do not use design values, but instead base severity of nonattainment on the "likelihood of compliance." For example, a designation of Moderate would result if a region was PM_{10} nonattainment before 1990 or is now PM_{10} nonattainment. A Serious designation for particulate nonattainment is given if EPA thinks the region will not meet its nonattainment deadline date to meet the primary NAAQS for PM_{10} ($PM_{2.5}$ in litigation).

State Implementation Plans (SIPs)

Under the Clean Air Act, EPA is required to establish National Ambient Air Quality Standards (NAAQS). In general, the 1970 amendments set June 30, 1975, as the date for attainment of these standards. Section 110 of the Act required all states to submit an implementation plan showing how attainment would be achieved and maintained by the statutory dates. These SIPs include emission limitations for stationary sources and control strategies, and form an enforceable commitment on the part of the states.

Attainment was not achieved in all areas by the 1975 deadline (or by a two-year extension to 1977), so Congress amended the Clean Air Act in 1977 to allow areas to continue the process of achieving compliance with air quality standards. Those areas that attained the standards prior to August 7, 1977, were required to maintain those standards, while the 1977 amendments further required EPA to designate nonattainment areas.

In nonattainment areas, Congress placed restrictions on the growth of sources and required SIP revisions to be submitted in order to demonstrate attainment on or before December 31, 1982 for all pollutants. If a state could demonstrate a need for carbon monoxide and ozone with mobile-source related problems, then that date could be extended to December 31, 1987.

Once again, many areas failed to attain the NAAQS by the required date, so Congress amended the Clean Air Act to impose new and more complex requirements in nonattainment areas. The 1990 Amendments emphasized an incremental approach to achieving attainment of the NAAQS. That is, attainment deadlines would be extended beyond those in the 1977 Clean Air Act Amendments, but states would now have to meet more stringent control requirements as an area's nonattainment problems become more severe.

The CAA requires states to develop and submit to EPA State Implementation Plans to demonstrate how they are going to meet the NAAQS.

The CAA required states to develop and submit to EPA State Implementation Plans to demonstrate how they would meet the NAAQS, and today States must show what reductions are necessary. This is accomplished by measuring pollutants in ambient air and comparing it to NAAQS, establishing emission inventories to tell what sources the emissions are coming from and the amount of emissions in a base year and the future attained year, conducting ambient air modeling to find what reductions are needed by the attainment year, and implementing those SIP provisions.

The CAA requires a SIP contain a variety of provisions. Among these are emission standards that ensure that a state's air quality does not violate NAAQS, develop an ambient air quality-monitoring network, conduct air quality modeling, create a nonattainment timetable for compliance, establish a permit system for new source review, and enforce procedures and policy. In addition to these general requirements for a SIP, nonattainment area SIPs must include "reasonably available control measures" (RACM), "reasonable further progress" (RFP), and an inventory of current emissions, etc. RACM requires that existing, stationary sources use "reasonably available control technology" (RACT), which takes into consideration technological and economic feasibility. Likewise, a SIP may also suggest more novel alternatives to standard emission control techniques such as market-based emissions trading programs. RFP plans must provide for such annual incremental reductions in emissions of nonattainment pollutants to assure reasonable further progress in attaining the NAAQS by the applicable date.

SIPs must be submitted to EPA for review and approval. If a state SIP does not meet the requirements of the CAA, EPA can reject the SIP and publish and implement its own Federal Implementation Plan (FIP). Additionally, EPA has several sanctions available that it can impose on states that fail to submit an approved SIP (highway funding terminated or new industrial projects must offset emissions at a 2 to 1 ratio). When EPA approves a SIP, it promulgates the SIP as a federal regulation. Once approved, a SIP remains federally enforceable unless both the state and EPA approve a change. If a state or local program fails to enforce any requirement of its SIP, EPA can then enforce it.

New Source Review: Permit Requirements

Under the Clean Air Act of 1970, states were required to have a permit system for pre-construction review of stationary sources. Besides establishing the New Source Performance Standards (NSPS) program, the 1970 Act dealt with permits in virtually a single paragraph, setting out a very broad requirement that states have a program for preventing the construction or modification of any source which would prevent the attainment or maintenance of a NAAQS. In contrast, the 1977 Amendments provided considerable detail as to what must be reviewed prior to the issuance of a permit. It established a new permit system for major emitting facilities constructed or modified in attainment areas (Prevention of Significant Deterioration) and in nonattainment areas. More detail to new source permit review was added by the 1990 Clean Air Act Amendments, which lowered the major source threshold for nonattainment areas with more serious nonattainment problems.

New Source Performance Standards (NSPS). Section 111 of the Act requires the EPA to publish a list of categories of stationary sources, which may contribute significantly to air pollution, or which cause or contributes to the endangerment of public health or welfare. At present there are 65 source categories identified.

The EPA must then propose regulations establishing standards of performance, called New Source Performance Standards (NSPS), for new sources within each category. The NSPS are nationwide emission limitations. These standards may be by design, equipment, work practice or operational standards where numerical emissions limits are not feasible. The NSPS must reflect “the degree of emission reduction achievable through application of the best system of adequately demonstrated” controls “taking into consideration the costs” of emission reduction. They are codified by the EPA at 40 CFR 60 on an industry-by-industry basis for each criteria pollutant.

Modification. NSPS apply to new and or modified sources. A modification is a physical change in operation of the source that will cause any increase in the emissions (calculated on an hourly basis). If emissions increase, the owner or operator may determine if an exemption applies. EPA has listed exemptions to what is a modification. The most important example is the routine maintenance, repair and replacement exemption (this exemption will also apply to PSD and Nonattainment programs). Under the EPA regulations, routine maintenance, repair, and replacement is not by itself a modification. Information about industry standards, replacement costs, and the like will be important information. However, EPA has recently made this exemption more difficult to apply by saying that it was intended to cover “frequent, traditional, and comparatively inexpensive repairs to maintain existing equipment.”

The “routine maintenance, repair, and replacement” exemption to NSPS has come under fire in recent years. The additional scrutiny has resulted in far more narrow interpretations of the regulation.

Therefore, existing sources, which do not change their process or modernize their equipment, do not increase their emissions and will avoid NSPS requirements. Existing sources, which do increase their emissions because of routine maintenance, repair, or replacement, may also avoid NSPS requirements if they meet the exemption requirements, which are now far more narrowly interpreted. The NSPS are nationally applicable and apply in both attainment and nonattainment areas. Enforcement of these standards is usually delegated to state and local agencies.

Prevention of Significant Deterioration (PSD). Prior to the 1977 Amendments, the CAA had no way to preserve those areas of the country with air quality cleaner than that prescribed by the NAAQS. The "purpose" of the CAA was said to "protect and enhance" the quality of the nation's air. The interpretation of this

provision was established in *Sierra Club v. Ruckleshaus (1972)* that held that EPA had a non-discretionary duty to prevent significant deterioration of air qualities in these clean areas. The court ordered EPA to revise all SIPs to prevent significant deterioration in these clean areas. In response to this opinion, EPA developed a new regulatory program to prevent "significant deterioration" of air quality. EPA proposed regulations outlining how PSD was to be implemented through state construction permit reviews. When Congress adopted Amendments to the Clean Air Act in 1977, it largely incorporated EPA's regulations into the Act. Therefore, the PSD program remains in the current CAA in Part C, Sections 160-169A. The PSD program establishes the following threshold for pre-construction review: *A major new stationary source in an attainment area must obtain a PSD permit*.

All new "major" sources are required to obtain a PSD permit to build. "New" sources are defined as any source having a "potential to emit" emissions of any regulated pollutant greater than 250 tpy or 100 tpy for 28 specified sources.

Major Source. A "major" source is defined as any source having a "potential to emit" emissions of any regulated pollutant greater than 250 tpy or 100 tpy for 28 specified sources. "Potential to emit" is the amount of a regulated pollutant that a facility emits based on the facility's maximum capacity of the source after taking into account the anticipated functioning of the air pollution control equipment and any permit limitations on the source's hours of operation.

In defining "source," EPA has adopted the "bubble rule" for PSD and nonattainment programs. It defines "source" to include the emissions of a regulated pollutant from the entire plant (like a bubble over the plant) and not each individual source of pollutants within the plant.

Major Modifications. A "new" source includes major modifications to an existing source. A major modification is defined as any change at a major source which will cause an increase of any regulated pollutant to exceed "significant" quantities (quantities listed by the EPA and calculated on an annual basis). A source will "net" their emissions to determine if contemporaneous changes to an existing major source will cause any criteria pollutant increase to exceed significant quantities. Netting is accomplished by adding up all source emission increases and decreases for five years prior to the beginning of new construction.

Attainment Area. An "attainment area," for PSD review, includes not only those areas that have reached attainment of the NAAQS, but also those areas that are "unclassifiable" (due to lack of information to determine whether the area meets the NAAQS). The area classifications are made on a pollutant-by-pollutant basis. Also, the same area may be a PSD area because it does meet the NAAQS for particulates and nonattainment because it exceeds the NAAQS for ozone.

BACT. A "PSD permit" requires that a new source will use the "best available control technology" (BACT) and that emissions will not exceed an "allowable increment." BACT is the "maximum degree of emission reduction…available" taking into account economic, energy and environmental factors. BACT must also be at least as stringent as the NSPS applicable to the same source category. BACT is determined on a case-by-case basis by the reviewing agency (most often the state agency); it is not detailed in the C.F.R. like NSPS are by the EPA.

A "PSD permit" requires that the new source use the "best available control technology" (BACT) and that emissions do not exceed an the NAAQS.

With respect to this BACT determination, EPA in December 1987 issued a guidance referred to as the "top down" BACT analysis. This is a 5-step process used by the source. The applicant first examines the most stringent "top" alternative, and then demonstrates that technical considerations, or energy, environmental, or economic impacts justify that this most stringent technology is not "achievable" in his case. Then, the next most stringent alternative is considered, and so on. The applicant's goal in this analysis is to provide the reviewing agency with sufficient information to verify and accept his proposed control options. To help air pollution professionals make these BACT determinations, EPA established the RACT/BACT/LAER CLEARINGHOUSE (RBLC) on its web site.

PSD Classification Areas (Class I, II, III). The permit application must also contain modeling information. It must show that the baseline concentration (background pollution concentration from all sources operating) plus contribution from the new source will not exceed the "allowable increment." In determining the "allowable increment" under the PSD program, areas are divided into three different classifications: Class I is the "cleanest" (i.e., national parks) in which only a small amount of degradation is allowed. Class II is "moderate" (i.e., most of U.S.) in which larger amounts of degradation are allowed. Class III is the "dirtiest" (i.e., industrial areas) in which the largest degradation is allowed, but never must it exceed the NAAQS. Section 163 of the CAA lists the "allowable increment" for each criteria pollutant. Therefore, the basic PSD requirement, as set out in Section 165 of the Act, provides that no new major stationary source for which construction is commenced after August 7, 1977, may be constructed unless:

a. A permit has been issued specifying the emission limitations.

b. An evaluation of existing air quality data has been conducted.

c. Certain specified air quality increments are not exceeded.

d. Best available control technology (BACT) is applied to the source.
e. The requirements for protection of pristine (Class I) areas are met.
f. There is an analysis of air quality impacts projected for the area as a result of growth associated with the proposed facility.

g. Monitoring will be conducted to determine the effect of the facility's emissions on air quality.

The "offset" provisions of the CAA permit industry to exchange new source emissions with reductions in existing emission levels within a nonattainment area.

Nonattainment Pre-Construction Review. The 1970 version of the CAA did not include any provision concerning nonattain-ment. It very optimistically set mid-1977 as the outermost date by which the NAAQS were to be attained. When the attainment date passed, many areas were found to be exceeding one or more of the air quality standards. Under the 1970 Act, the only course of action available was to revise the applicable SIP to ensure attainment and maintenance of the standards. The states and EPA were then faced with the question of what to do about the growth in nonattainment areas during the period in which the SIPs were being revised. To address this problem, EPA developed regulations on "emission offsets." Although there was no provision in the 1970 CAA for such a concept, EPA viewed it as a compromise alternative to a no-growth policy. Congress apparently agreed, because the 1977 amendments specifically adopted the requirements of EPA's policy on new sources in nonattainment areas. The 1977 Amendments required these new major sources, among other things, to meet strict emission limits and to "offset" their new emissions by a reduction in the emissions from other sources in the same nonattainment area. In addition, Congress extended the compliance date for nonattainment areas to 1987.

Once again, many areas failed to attain the NAAQS by the required date. As a result, Congress, in 1990, amended the CAA. The 1990 Amendments modified the nonattainment provisions of the 1977 Amendments. States must now include in their SIP plan, a special graduated control program for ozone, carbon monoxide and particulates. The more serious the noncompliance, the more stringent the control measures would be imposed.

The rule for pre-construction review in nonattainment areas is as follows: *A major new stationary source in a nonattainment area must obtain a nonattainment permit*. A "major" source is defined as any source, which has a potential to emit emissions of any nonattainment pollutant greater than 100 tpy, or lower depending on the nonattainment classification (i.e., 50 tpy for volatile organic compounds [VOC] and nitrogen oxides [NOx] in serious ozone nonattainment areas, 25 tpy for Severe areas, and 10 tpy for Extreme areas). "Potential to emit," and "source" are defined the same as in the PSD program. “New” is also the same as in the PSD program, except in ozone, carbon monoxide, and particulate nonattainment areas, which decrease the allowable “significant quantities” for a major modification to an existing source (i.e. in ozone Serious or Severe areas: significant quantity is 25 tpy VOC; in extreme areas there is no significant quantity allowed). A “nonattainment permit” requires all the following:

LAER. Sources must meet the most stringent, technology-based level of control called “lowest achievable emission rate” (LAER). In determining LAER, the reviewing authority must consider the most stringent emission limitation contained in any SIP in the country and the lowest emission, which is achieved in practice by the same or similar type of source. Applicants select LAER in a similar manner as BACT, except that there is no consideration of economic, energy, or environmental factors. The only consideration is whether the cost of a proposed emissions control is so prohibitive that it has never been applied at any other source because it would have been too expensive to build.

Complete Compliance. All existing major sources, in the same state, that are owned or controlled by the owner or operator of the proposed source must be in compliance with all applicable requirements under a SIP and the CAA.

Emission Offset Requirement. The proposed new source must offset its emissions from existing sources in the area (whether or not under the same ownership); so that the company is taking out of action more emissions than they propose to put in. In ozone, especially in particulates and carbon monoxide nonattainment areas, the 1990 amendments imposed higher offset requirements as the nonattainment classification becomes more severe (i.e., offset ratio for VOC is 1.1 to 1 in Marginal ozone nonattainment areas; offset ratio for VOC is 1.3 to 1 in Severe ozone nonattainment area).

Hazardous Air Pollutants

Under the 1970 CAA, Section 112 required the Administrator of EPA to establish standards for air pollutants for which no ambient air quality standard is applicable and which, in the judgment of the Administrator, may cause or

HAPs are pollutants that have no ambient air quality standard but may cause or contribute to increased human mortality or serious illness.

contribute to "an increase in mortality, or an increase in serious irreversible, or incapacitating reversible, illness." The EPA was required to promulgate a list of pollutants that met this statutory definition of “hazardous air pollutants” (HAP) and to develop “National Emission Standards for Hazardous Air Pollutants” (NESHAP) that would provide an “ample margin of safety to the public health.”

This health-based standard could be read to preclude considerations of cost or technological feasibility, and possibly to require (in cases of scientific uncertainty about safety of exposure levels) the establishment of zero-risk level for emissions. This vagueness left EPA’s regulations open for challenge by both industry as too harsh and environmentalist as too lax. As a result, EPA had a difficult time implementing the NESHAP requirements. Between 1970 and 1990, EPA only promulgated NESHAPs for eight pollutants: asbestos, benzene, beryllium, mercury, vinyl chloride, coke oven emissions, inorganic arsenic and some radionuclides.

In the 1990 CAA, under Section 112, Congress completely changed the approach to hazardous air pollutants from a health-based to a technology-based regulation. In these Amendments, Congress now defined a hazardous air pollutant as “any air pollutant listed in Section 112 (b).” In this section, 189 substances were listed as hazardous air pollutants. EPA may add or delete pollutants from this list based on a determination that these substances may cause “adverse effects to human health or the environment.” Substances can also be added or deleted by an individual who petitions the EPA.

These Amendments required EPA to publish a list of categories and subcategories of major and area sources of hazardous air pollutants. In July 1992, EPA published an initial list of 174 major source categories and 8 area source categories of hazardous air pollutants. These Amendments also required EPA to pass technology-based emission standards (called MACT) for each of these listed HAP source categories according to a statutory schedule. The schedule also required that all source categories must have MACT standards promulgated by the year 2000. In September 1992, EPA followed the source category list with a schedule for promulgation of emission standards, which specifies when each of the listed source categories will be regulated.

If EPA fails to promulgate a MACT according to the source category schedule, then the “MACT hammer” applies: This hammer mandates that 18 months after MACT due date, major sources must meet a MACT standard that is determined by the state on a case by case basis.

NESHAP rules are now technology-based standards that must use the “maximum achieveable control technology.”

Under 1990 CAA, section 112, NESHAPs are now to be established as *technology-based* standards based on “maximum achievable control technology” (MACT), taking into consideration the cost of achieving such emission reduction. MACT standards are promulgated by the EPA and codified at 40 CFR 63 by source category (i.e., MACT for dry cleaning operations is at 40 CFR 63 Subpart M).

The MACT standards may differ for new and existing sources within a source category. For new sources, the standard must be based on the “best controlled similar source.” New sources must comply with MACT immediately. A “new source” is any source that is constructed or modified after the date of the proposed MACT. For existing sources, the standard must be based on the emission limits achieved by the “best controlled 12% of existing sources.” Existing sources have up to three years to comply. The MACT standard may be further subcategorized and differ depending possibly on the size of the source or other factors within a particular source category. For example, the MACT for dry cleaning operations does not require *small existing* sources to have a process vent control, whereas *large and major existing* sources must use a refrigerated condenser as process vent control device. This MACT also requires that *small and large new* sources use only a refrigerated condenser control device, and that a *major new* source utilize both the refrigerated condenser and carbon adsorber as control devices on the process vents.

“Major sources” of hazardous air pollutants must meet MACT limitations. Under this program, a “major source” is defined as any stationary source having the potential to emit more than 10 tons per year of any listed HAP or 25 tons per year of any combination of the listed HAP. An “area source” is any source stationary source of HAP that is not a major source. Many area sources are likely to be regulated under EPA’s urban air toxic strategy.

The 1990 Amendments authorizes EPA to establish additional requirements to control any “residual risk” that exists after eight years after promulgation of MACT. The EPA will conduct a risk assessment to determine if any residual risk remains to the public health. If a risk remains, then EPA must pass an additional *health-based* standard that will provide an “ample margin of safety” to the public. These second-tier standards are known as “residual risk” standards. In addition, the 1990 Amendments developed additional regulatory programs concerning hazardous air pollutants. One of them is the “early reduction program.” This program offers industry an incentive to reduce their HAP emissions before a MACT is imposed. If a company reduces its HAP emissions by 90% (gaseous) and 95% (particulate), and adjusts for high-risk pollutants, then the company is given six years after MACT is promulgated to comply with MACT.

Another HAP regulatory program, established by the 1990 Amendments, concerns the prevention of accidental release of extremely hazardous substances. This program required EPA to develop a list of at least 100 substances that pose the greatest risk of causing death or serious injury (listed at 40 CFR Part 68). Facilities that use these extremely hazardous substances, above an established threshold limit, must prepare and implement a risk management plan. This plan mainly establishes a response program in the event of a release of these listed hazardous substances. Enforcement of these hazardous air pollution programs is often delegated to state and local agencies.

The PSD program identifies at least 100 substances that pose the greatest risk to death or serious injury. Facilities that use these substances must develop a risk management plan to protect against accidental release or exposure.

Acid Rain Program

Acid rain results when fossil-fuel burning plants emit sulfur dioxide and nitrogen dioxide. These substances can be transported hundreds of miles before they return to earth as sulfuric or nitric acids in wet (rain) or dry precipitation. The effects of acid rain include acidification of lakes as well as damage to forests, man-made materials, and health. The 1990 Amendments created the Acid Rain Program. The purpose of this program is to reduce acid rain that is formed from sulfur dioxide and nitrogen oxides emissions to the atmosphere by reducing these emissions from fossil fuel-fired steam generating units.

Sulfur Dioxide Emission Reduction Program

This program imposes a national emission cap of 8.95 million tpy of SO_2 from electric utility power plants to be achieved in 2 phases (phase 1 to take effect by 1995 and phase 2 to take effect by 2000). Phase I mandates that 107 utility power plants (those with the highest SO2 emissions and listed in the 1990 CAA) must meet SO2 emission limit of 2.5 lbs/mmBtu. Phase II is more stringent and far reaching than Phase I: existing coal fired electric utilities must meet SO2 emission limit of 1.2 lbs./mmBtu., and a new coal fired electric utility cannot emit any SO2 or receive any allowances from EPA (they must purchase their allowances).

This program establishes a "marketable trading" plan for SO2. Sources subject to emission limitations under this section are assigned SO_2 "allowances" by statutory formula. An allowance is an authorization to emit one tpy of SO_2. Allowances are traded at an auction by those eligible to hold allowances. The purpose of the “marketable trading” program is to allow power plants the flexibility necessary to determine how to best comply with emission reductions. They can install a pollution control device, convert to low sulfur fuel, or purchase additional allowances to meet their SO_2 limits. If a source reduces its sulfur oxide emissions below its baseline, it may receive sulfur oxide allowances, which can then be sold.

The purpose of the “marketable trading” program of SO_2 emissions is to allow power plants flexibility in determining how to comply with emission reductions.

Nitrogen Oxides Emission Reduction Program

Sources which are subject to the sulfur allowance program are also required to reduce nitrogen oxide emissions. The 1990 Acid Rain Program required EPA to set NOx emission limits for fossil fuel-fired steam generating units subject to the Phase 1, SO_2 program. It also required EPA to promulgate annual allowable emission limitations for nitrogen oxides for certain types of utility boilers.

Operating Permit Program

The NPDES permit program requires all major stationary sources of pollution to obtain an operating permit.

In the 1990 Amendments, Congress adopted a permit program modeled after the National Pollution Discharge Elimination System (NPDES) permit program. These permit requirements, called the operating permit program, are now contained in Title V, Sections 501 to 507. This program requires states to develop and implement an operating permit program for "major" stationary sources of air pollution. States had until November 15, 1993 to adopt an operating permit program and submit it for EPA approval. EPA must then approve or disprove the state program within one year after submittal.

Title V of the CAA required the following "major" stationary sources to obtain an operating permit:

a. Major source (emits or the potential to emit greater than 100 tpy)

b. Major source under HAP, PSD, or nonattainment provisions

c. Any source regulated under acid rain, area sources under HAP, NSPS provisions and any other source designated by the EPA

Title V required an operating permit "application" must include all of the following:

a. A list of all pollutant emissions for which the source is major and all emissions of regulated air pollutants

b. Identification of all points of emissions

c. Emission rates in type and in other terms necessary to establish compliance

d. Description of air pollution control equipment

e. Identification of all air pollution control requirements

States have 18 months to take final action on an operating permit application. An operating permit must be issued for a fixed term of up to 5 years. In addition, states can charge permit fees for the implementation and enforcement cost of the permit program. This fee must be at least $25 per ton of regulated pollutant. If a company fails to obtain an operating permit, this will cause fines up to $10,000 per day for each violation.

Title V required that an operating “permit” must contain all of the following:

a. Applicable emission limitations and a compliance schedule,

b. Monitoring and related record keeping and reporting requirements, and

c. Any other conditions that are necessary to assure compliance with the CAA.

Stratospheric Ozone Program

Title VI of the 1990 CAA addresses stratospheric ozone depletion. It establishes a program to protect stratospheric ozone by phasing-out over a period of time the production and sale of ozone depleting chemicals, generally along the lines called for by the *Montreal Protocols*. According to the CAA, ozone-depleting chemicals are classified as either Class I or Class II substances. Class I substances include five groups specified in the 1990 Amendments plus certain chlorofluorocarbons, halons, methyl chloroform, and carbon tetrachloride. EPA can add substances to this list based on a finding that the substance "causes or contributes significantly to harmful effect on the stratospheric ozone layer." Class II substances include 33 hydrochlorofluorocarbons and their isomers. EPA can add substances to this list based on a finding that the substance "is known or may reasonably be anticipated to cause or contribute to harmful effects on the stratospheric ozone layer."

The Stratospheric Ozone Program will phase out the production and consumption of all Class I and II substances that significantly damage the stratospheric ozone layer.

The Stratospheric Ozone Program calls for phasing out the production and consumption of Class I and II substances. Beginning in 1991, it is unlawful for any person to produce or import any Class I substance in any quantity greater than certain percentages specified in the CAA. Beginning in 2000, all production of Class I substances is prohibited. Class II substances are to be phased out by 2030. Exceptions are made for limited quantities of halons solely to test for corrosion on airplanes and the Class I and Class II substances necessary for use in medical devices. Phase-out will be achieved through the use of transferable "allowances" for the production of Class I and II substances. The EPA will reduce the number of "allowances" so that production of the substances will be phased-out by the appropriate deadline.

Visibility Protection Program

The 1977 CAA Amendments (Section 169) established a national goal of eliminating any man-made visibility impairment in mandatory Class I areas, and required states make reasonable progress towards attaining this goal. States were required to develop best available retrofit technology (BART) and a long-term strategy to be submitted as part of their SIP plan. In 1980, EPA passed regulations addressing the criteria for SIPs concerning visibility impairment in a Class I areas.

The 1990 CAA Amendments also addressed visibility protection. As a result of these Amendments, EPA in 1999 passed regulations (40 CFR 51.308-.309) requiring haze-contributing sources to install BART and for states to adopt regulatory programs to achieve EPA-established targets concerning visibility improvement.

Mobile Sources

Federal legislation to regulate automobile emissions existed prior to 1970, but the 1970 CAA established the basic structure of mobile source controls. Section 202 of the CAA authorizes EPA to establish motor vehicle emission standards and to test vehicles for compliance (or require manufacturers to perform such testing). With the exception of California, the CAA preempts states from establishing their own mobile source emission limits. Section 211 of the CAA authorized EPA to regulate the composition of automobile fuels. EPA responded by phasing out lead in gasoline.

The 1990 CAA Amendments required more stringent tailpipe standards. Manufacturers were required to reduce hydrocarbon and nitrogen oxides emissions by 35% and 65%, respectively. The Amendments also established the Reformulated Fuel program, which required the use of reformulated gas in certain carbon monoxide and severe ozone nonattainment areas; the Oxygenated Fuels program for use in carbon monoxide nonattainment areas; and the Clean Fleet program, which required "fleets" of automobiles to use clean alternative fuels (i.e., ethanol) in a certain classification of carbon monoxide and ozone nonattainment areas.

The 1990 CAA Amendments require all automobile manufacturers to reduce hydrocarbon and NOx emissions by 35% and 65%, respectively.

Federal Enforcement

Civil Action. Section 113(b) of the CAA provides that EPA can initiate civil actions for past and ongoing violations. These actions are brought by the Department of Justice (DOJ) in U.S. District Court for appropriate relief, including a permanent or temporary injunction, and/or a civil penalty of not more than $25,000 per day of violation. These violations can be of the requirements and prohibitions contained in the state implementation plans and permits as well as the rest of the requirements in the CAA.

Administrative Penalties. As a result of the 1990 Amendments, the EPA, under Section 113, now has broad authority to impose administrative orders and penalties on alleged violators without going to court. Section 113(a), allows EPA to issue an "administrative compliance order" (ACO) for most violations of the CAA (except Title II, Mobile Sources). Except in cases concerning HAP, the ACO is not effective until a conference is held with the violator to discuss the order. Failure to comply with an ACO may subject the source to civil penalties. However, EPA must first initiate separate civil, judicial, or administrative action pursuant to Sections 113(b) or 113(d), collect penalties, or mandate compliance with the ACO. Judicial review of an ACO is unavailable because it not considered a "final action.

EPA may impose civil penalties for violations of the CAA up to $25,000 per day, not to exceed $200,000. EPA may also issue field citations for minor violations of up to $5,000 per day.

New, under the 1990 Amendments, Section 113(d) of the CAA authorizes EPA to issue "administrative penalty orders"

(APO) of up to $25,000 per day of violation with a cap of $200,000. An APO can be issued for any violation of the CAA except Title II, Mobile Sources. Upon receipt of an APO, a violator has 30 days to request an administrative hearing with the EPA. This hearing will be held according to the procedures required by the Administrative Procedure Act. This "administrative penalty order" is appealable by filing with the U.S. District Court within thirty days. Section 113 also authorizes EPA to issue "field citations" for minor violations observed in the field. Fines can be issued for up to $5,000 per day of violation with fewer procedural requirements.

Criminal Action. The CAA's criminal sanctions provision under Section 113 has been substantially changed by the 1990 Amendments. "Knowing" violations of the CAA can result in fines of up to $250,000 for individuals and $500,000 for corporations per day of violation, and up to five years imprisonment. Knowingly falsifying reports, or failure to keep necessary monitoring records or permitting material omissions from such reports and records, can result in the same fines and up to two years imprisonment. "Knowing" failure to pay a fees or administrative fines can also result in fines of up to $100,000 for individuals and $500,000 for corporations per day of violation and up to one year imprisonment.

Criminal penalties for the intentional or negligent release of air pollution may result in fines up to $1M and 15 years imprisonment.

Section 113 also now imposes criminal penalties for "knowing" or "negligent" releases of hazardous air pollutants into the ambient air and "knowingly" placing another person in "imminent danger of death or serious bodily injury." For a "knowing" release, fines can be as much as $250,000 for an individual and $1,000,000 for a corporation per day and up to 15 years imprisonment. For a "negligent" release, fines can be as much as $100,000 for an individual and $200,000 for corporations per day and up to one year imprisonment.

Citizen Suits. Under Section 304, citizens may sue after giving at least a 60-day notice to the pollution source, EPA, and state. They can sue pollution sources for non-compliance with an emission standard or order issued by the EPA. They can sue the EPA for failure to perform any non-discretionary acts required by the CAA. As a result of 1990 Amendments, Section 113(f), a citizen may now receive a reward of $10,000 for giving information to EPA that leads to successful criminal or civil suits.

EPA Emergency Powers. The pre-1990 CAA, Section 303 provided that when a pollution source is presenting "imminent and substantial endangerment to the health of persons," and the "appropriate state or local authorities have not acted to abate such sources," the Administrator may bring suit to immediately restrain the violation. EPA has rarely used this provision, but the 1990 Amendments now allow these emergency orders when there is “imminent and substantial endangerment to the public health or welfare or the environment,” and do not require the EPA to allow state or local authorities to address the situation.

NAME____________________________________DATE_____________SCORE__________

CHAPTER 5 United States Clean Air Act

Multiple Choice

Directions: *Read each question and choose the best answer. Write the letter of your answer in the space provided.*

1. The Clean Air Act does **not** regulate _______.

a. emissions that enter the inside air
b. fugitive emissions that are released to the atmosphere
c. emissions from a chimney released directly to atmosphere
d. emissions from a factory that is vented to atmosphere
e. emissions from a school that is vented to atmosphere **1.** ________

2. Which of the following is **not** a criteria pollutant with a NAAQS?

a. Ozone
b. PM-10
c. Asbestos
d. Carbon monoxide
e. Lead **2.** ________

3. Which of the following must be considered when establishing a NAAQS?

a. Protection of the average person
b. Cost to implement
c. Availability of control equipment
d. Enforcement procedures
e. Protection of the most sensitive person **3.** ________

4. Nonattainment classifications of ozone and carbon monoxide are determined by their _______.

a. design values
b. highest ambient air concentrations in the last year only
c. emissions inventories
d. likelihood of compliance
e. enforcement procedures **4.** _______

5. The CAA requires that a state implementation plan (SIP) be reviewed and approved by EPA. If the state fails to produce an acceptable SIP, then _______.

a. a federal implementation plan will be developed
b. a state can be fined
c. a similar state strategy will be implemented
d. no new sources of pollution will be allowed in state
e. enforcement procedures will be implemented against the state **5.** _______

6. Which of the following areas apply to New Source Performance Standards (NSPS)?

a. nonattainment areas
b. attainment areas
c. unclassifiable areas
d. all of the above
e. none of the above **6.** _______

7. The legislation that created provisions for the Prevention of Significant Deterioration (PSD) was the _______.

a. Clean Air Act (1963)
b. Air Quality Act (1967)
c. Clean Air Act Amendment (1970)
d. Clean Air Act Amendment (1977)
e. Clean Air Act Amendment (1990) **7.** _______

8. A nonattainment permit does **not** require which of the following:

a. Best available control technology (BACT)
b. Lowest achievable emission rate (LAER)
c. Complete compliance of owners other sources in same state
d. Offset emissions
e. None of the above **8.** _______

9. Which of the following must be taken into consideration when establishing a maximum achievable control technology (MACT) standard?

a. Health impact on the most sensitive person
b. Technology based standard considering costs of achieving emission reduction
c. Only the health effects on people
d. Ample margin of safety to protect the protect the public health
e. None of the above **9.** _______

10. Which of the following programs is regulated by the CAA?

a. Acid rain
b. Manmade visibility in certain Class I areas
c. Stratospheric ozone
d. Automobile emissions
e. All of the above

10. _______

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	A	5-3
2.	C	5-3
3.	E	5-4
4.	A	5-5
5.	A	5-7
6.	D	5-8
7.	D	5-8
8.	A	Many places
9.	B	5-14
10.	E	Entire Chapter

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CHAPTER 6

Ambient Air Quality Monitoring

Lesson Goal

Demonstrate an understanding of the design strategies, methods, regulations, and networks of ambient air quality monitoring by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Discuss how ambient air quality monitoring data are used.
2. Describe an ambient air-monitoring network.
3. Explain how monitoring sites are selected.
4. Describe an ambient air quality monitoring network and its major subsystems.
5. Distinguish between a reference and an equivalent measurement method.
6. Explain the purpose, findings, and recommendations of the SAMWG.
7. Outline the contents of 40 CFR 58 air-monitoring regulations.
8. List four air pollution-sampling techniques.
9. List and explain three methods of gas collection.
10. Discuss three examples of particulate matter collection.

Recommended Reading: Godish, Thad, “Air Quality and Emissions Assessment,” *Air Quality*, 3rd Edition, New York: Lewis, 1997, pp. 215-236.

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Ambient Air Quality Monitoring

The primary goal of any air pollution control program is to protect people and their environment from excessive exposure to atmospheric pollutants. Evaluating the success or failure of pollution control programs largely depends on the availability of accurate data about ambient (outside) concentrations of air pollutants or air quality. Consequently, an entire body of research has emerged that attempts to better estimate the quantity and types of pollutants in the ambient air, and to better characterize and quantify the specific sources of those pollutants.

The purpose of any air pollution control program is to protect human health and welfare.

Air Quality is a dynamic and complex environmental phenomenon exhibiting large temporal and spatial variation. The temporal and spatial variations in atmospheric levels of pollution, which is the essence of air quality, are caused by (a) changes in the pollutant source(s) emission rates, and (b) changes in meteorology and topography, which provide the mechanisms for chemical reactions of pollutants in the atmosphere and for the control and removal of atmospheric pollutants. Monitoring of the air quality can be very complex, since it requires the collection of data that allows for a resolution of the dynamic nature of air quality in terms of its spatial and temporal variation.

Ambient air quality monitoring can be defined as a systematic, long-term assessment of air pollutant levels in our communities. This monitoring is usually undertaken to characterize air quality in urban areas, near large point sources of air pollution or where there are sensitive environmental receptors. The ability to assess the air quality of a region will depend on accurate and representative data describing existing conditions and dispersion models, which can be used to better predict future pollution levels. In general, ambient air monitoring networks are typically used to:

- characterize local, regional, and national air quality conditions
- assess health impacts
- assess effectiveness of control programs
- help form the basis for new control programs
- assess source impacts
- provide information to the public

The Mellon Institute, of Pittsburgh, Pennsylvania (1912), conducted one of the first air quality measurements and analyses of deposited dust fall in the United States. The first gaseous automatic sampling equipment was not used until the late 1920s for sulfur dioxide. This equipment was used in a network of instruments so that combined wind direction could be taken into account as an added variable factor.

The first official use of an ambient air monitoring network was employed by the Los Angeles Air Pollution Control District in 1955.

In 1955 Los Angeles County Air Pollution Control District established an air-monitoring network of one mobile and ten-fixed air sampling stations. The individual sites were equipped with radio transmitters that could activate alarms when preset monitoring levels were exceeded. In 1970, Congress passed the Clean Air Act (CAA) and established the National Ambient Air Quality Standards (NAAQS), which were established to provide air quality sufficient to protect human health and welfare.

The CAA directed EPA to set primary and secondary standards that would “provide an ample margin of safety” and require EPA to establish acceptable levels of concentration or “criteria” in the ambient air for five pollutants. Those five pollutants were: sulfur dioxide (SO_2), particulate matter (TSP), carbon monoxide (CO), ozone (O_3), and nitrogen dioxide (NO_2). In a later version of the act, lead (Pb) was added and ozone was adopted as the photochemical oxidant indicator of volatile organic compound (VOC) precursors.

There are two types of ambient air standards – primary standards and secondary standards. As stated in Section 109 of the CAA, primary standards are those in which “the attainment and maintenance…is requisite to protect the public against adverse health effects.” Secondary ambient air quality is defined as “a level of air quality which is required to protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutants in the ambient air.” The purpose of the secondary standard is to provide broader protection to the public and protect the environment from long-term damage. With sulfur dioxide (SO_2) as the only exception, the U.S. EPA has established only one level for both the primary and secondary standard. Collectively, these standards form the National Ambient Air Quality Standards (NAAQS).

Table 6-1. National Ambient Air Quality Standards

Pollutant	Primary Standard (Health Related)		Secondary Standard (Welfare Related)
	Average	Std. Level Concentration	
CO	8-hour	9 ppm (10 mg/m^3)	No Secondary Standard
	1-hour	35 ppm	No Secondary Standard
Pb	Maximum Quarterly Average	1.5 ug/m^3	Same as Primary Standard
NO_2	Annual Arithmetic Mean	0.053 ppm (100 μg/m^3)	Same as Primary Standard
O_3	Maximum Daily 1-hr Average	.12 ppm (235 μg/m^3)	Same as Primary Standard
	4th Max. Daily 8-hr Average	0.08 ppm (157 ug/m^3)	Same as Primary Standard
PM_{10}	Annual Arithmetic Mean	50 μg/m^3	Same as Primary Standard

	24-hour	150 μg/m^3	Same as Primary Standard	
$PM_{2.5}$	Annual Arithmetic Mean	15 μg/m^3	Same as Primary Standard	
	24-hour	65 μg/m^3	Same as Primary Standard	
SO_2	Annual Arithmetic Mean	0.03 ppm (80 μg/m^3)	3-hour	0.50 ppm (1300μg/m^3)

A standardized NAAQS was first promulgated in 1971.

In August of 1971, the Environmental Protection Agency promulgated regulations for preparation, adoption, and submittal of SIPs under Section 110 of the CAA. Included in these regulations were the requirements for states to establish and operate ambient monitoring networks and report the data to EPA. These data were to be used for such purposes as evaluation of National Ambient Air Quality Standards (NAAQS), reevaluation of the NAAQS, development of national strategies, activation of emergency control procedures provide a database for research and evaluation and the preparation of national trends in ambient air quality.

The primary and secondary ambient air quality standards must be achieved throughout the United States and its possessions. In order to meet these standards, states were required to develop and implement air pollution control strategies through the mechanism of the State Implementation Plans (SIPs). The implementation plans may contain control strategies such as: industrial and urban zoning, the development or expansion of mass transit systems and vehicle inspection and maintenance programs, and the establishment of stationary source emissions standards for specific industrial categories.

Ambient air monitoring plays a vital role in the development and evaluation of these control strategies. During the development phase, air quality data is used to determine whether an area is attaining or not attaining the air quality standards. The determination is critical for the proper designing of control strategies for an area in question because attainment areas usually require less stringent control measures than nonattainment areas. Furthermore, air quality data may be used to generate or validate air pollution dispersion models, which are then used in the development of control strategies.

In the mid-1970s, several critical reviews of environmental monitoring programs identified major deficiencies in several aspects of the existing monitoring systems. A Standing Air Monitoring Work Group (SAMWG) was formed to review and provide recommendations to overcome these deficiencies. The work group prepared a list of the major activities of an air-monitoring program and then used these as the basis for writing a series of nine issue papers. SAMWG prepared a final draft of an overall air monitoring strategy for SIPs in December 1976. This drafted document was circulated for review by the 50 states, and 180 local agencies and EPA offices.

The SAMWG prepared a list of major activities of a quality air monitoring program, which became the basis for current monitoring networks.

Workshops were also held to provide an opportunity for open discussions about the overall concepts of the strategy. The final air-monitoring document that was formally approved by the Administrator reflected the deliberations of workshops and comments that were received on the draft strategy. The primary goal of the strategy was to ensure that air quality managers at all levels had reliable air quality data and information. It also served as a blueprint for proposing changes in the Agency’s regulations covering state and local agency air quality surveillance and data reporting.

In addition to determining compliance with air standards, air quality monitoring can also be used to determine the following information: (1) document a facility’s progress toward compliance, (2) establish baseline pollutant levels for controlled substances, (3) control policy development, (4) provide short-term data requirements for episode control plans, (5) provide valuable data to epidemiological studies designed to establish the relationship between pollutant levels and the human health and welfare effects of exposed populations, (6) determine the Air Quality Index (AQI) for reporting the daily air quality to the public, (7) confirm air pollution modeling validation, and (8) assess trends in the atmospheric levels of regulated and unregulated pollutants.

Monitoring networks are also operated to determine the impact of new emission sources. Air quality monitoring with these networks can be used as part of the Prevention of Significant Deterioration (PSD) process to assess the impact of a new source on existing air quality. Measurement of suspended particulate matter in the ambient air is most likely one of the oldest forms of air quality sampling and therefore has been monitored more extensively than other pollutants. Particles can be collected by gravitational settling, filtration, impaction, electrostatic and thermostatic precipitation.

Particulate Matter Collection

Impaction is a principle of particulate matter collection and sampling in which particles are drawn through a device, but deflected from their original path.

Filtration and impaction are and have been the most widely used for sampling particulate matter. A primary advantage of filtration is the feasibility of handling large volume rates of flow. Also, sample that has been collected and filtered is usually readily available for direct observation using microscopy, or analyzed physically or chemically. Due to the potential adverse health effects of very small particles, particle sizing or particle size distributions of inhaled air are of significant interest. Very large particles (approximately 15μm or larger) suspended in inhaled air, are removed in the nose and throat, and thus do not reach the lungs.

Particles that are approximately 10μm and smaller are inhaled into the lower respiratory system. Particles in the ambient air have an idealized or tri-modal distribution with regard to particle size. This particle size distribution appears to have peaks at about 10μm, 0.4μm, and 0.01μm. The larger particle size fraction includes a significant portion that is caused by natural processes such as erosion. The smaller particles or fine fraction are usually manmade (anthropogenic) consisting of combustion and industrial emissions. Hence most man-made particles can be inhaled into the lower respiratory system and are usually the particles that pose additional health hazards (i.e., heavy metals and polynuclear hydrocarbons).

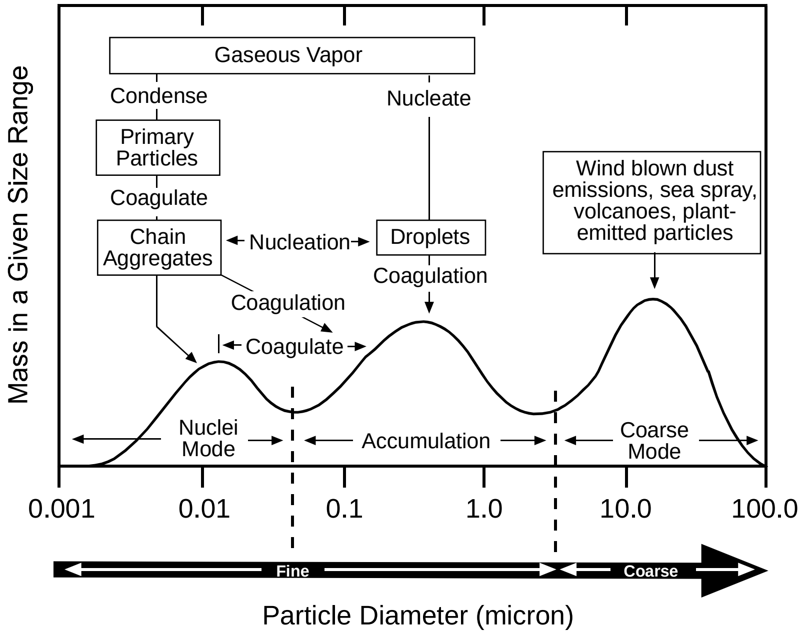


Figure 6-1. Size Distribution and Sources of Atmospheric Particles

Several types of particulate matter samplers are designed to sample only the smaller size (<10μm) particles because of their health implications. These samplers are the PM_{10} sampler, which stands for particulate matter less than 10μm in diameter. PM_{10} samplers are high-volume (40 cubic feet per minute) with an inlet head arranged to remove the larger particles through an impaction and gravity-settling chamber before reaching the filter. Other particle samplers, such as the dichotomous or virtual impactor, the cascade impactor, and the continuous PM_{10} samplers are also used to quantify the concentration of fine (<2.5μm) particles in the ambient air.

A high-volume sampler is a device used to sample particulate matter in which pollutants are drawn through a glass fiber filter using a vacuum motor to draw the air.

Gaseous Pollutant Collection

Collection of gases can be accomplished by absorption, adsorption—in an evacuated container (grab sampling)—or by condensation. The method of choice will depend largely on the physical properties of the gas of interest. Absorption is particularly important, in the wet-chemical methods analysis. Prior to the advent of continuous monitoring instrumentation, the techniques employing absorption were the most inexpensive and up-to-date methods available. Absorption of gaseous pollutants has been used quite extensively in atmospheric sampling because of the numerous methods available to analyze the resulting solution.

Adsorption is a sampling technique used to collect ambient air gases with a collection tube containing solid surfaces such as carbon, silica gel or molecular sieves.

Adsorption is the process by which gases are attracted, concentrated, and retained at a boundary surface. In air pollution monitoring, adsorption techniques are commonly used for collecting a specific gas or combination of gases. A typical process consists of removing a gas from flowing air stream through a container filled with an adsorbent such as activated carbon, silica gel, or molecular sieve. Following collection, the gas may be removed from the adsorbent for analysis by applying heat, passing inert carrier gases through the system, or treating chemically. Static or passive sampling is a collection method where gases are collected by diffusion on to a collection medium, the settling of large particles into a container, or impaction of particles on sticky paper. Static sampling is used because it has advantages of simplicity and low cost. However, because of long averaging times (up to 30 days) and its semi-quantitative methodology, static sampling data are limited in their usefulness.

Evacuated containers for grab sampling made of glass, stainless steel or other non-reactive materials can also be used to collect non-condensable gases; however, the methods of collection depend upon the specific gas properties involved. Gases may also be collected by condensation or cryogenic trapping. This method consists of essentially drawing the air stream through collection chambers with progressively lower temperatures. If the temperatures of the chambers are approximately equal to or less than the boiling point of the gaseous components or the air passing through it, these components will condense to a liquid phase.

The most commonly used non-continuous methods of gas collection and sampling is through absorption using bubblers or impingers, adsorption with solid adsorbing materials, or grab sampling in evacuated containers.

The designated EPA Federal Reference Methods (FRM) for sampling and analysis of pollutants measured from the ambient air for Criteria Pollutants (i.e., Particulate Matter – $PM_{2.5}$ and PM_{10} – Lead (Pb), Sulfur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Ozone (O_3), and Carbon Monoxide (CO), can be found in 40 CFR part 50 Appendices A through M. These methods specify the measurement that must be followed in order to determine compliance with the primary and secondary National Ambient Air Quality Standards.

In addition to reference methods, equivalent methods may be used that have been designated to measure equivalency to the reference method. Equivalent method designation may be either manual or automated. If a manual method is to be considered for equivalency, it must demonstrate a consistent relationship to the reference method when both methods are used to measure pollutant concentrations in a real atmosphere. For automated methods, each instrument must meet specific performance specifications. Instrumental or automated methods have assumed the prominent role in monitoring gaseous pollutants in air. Real-time data output, greater sensitivity in meeting the requirements of specific applications and the ability to transmit data directly into computer systems represent major advantages of instrumental methods over manual methods. Some of the instrumental methods currently used for ambient air monitoring are chemiluminescence, nondispersive infrared and ultraviolet florescence.

The general requirements and specifics for equivalent method determinations can be found in 40 CFR Part 53, Subparts A through F. In addition, lists of designated reference and equivalent methods can be found on the Air Monitoring Technical Information Center (AMTIC) web site, located at http://www.epa.gov/ttn/amtic/.

Another important parameter in ambient air monitoring is averaging times for sampled pollutants. The averaging times used for determining pollutant concentrations is typically determined by the duration required to collect a meaningful sample and by the intended use of the collected data. For example, 24-hour averages would be appropriate for long-term air quality trends. For pollutants that reach peak levels for short periods of time such as O_3, a 1 hour or 8 hour averaging time would be more desirable. Real-time or continuous air monitoring instruments provide a continuous record of concentrations that can fluctuate over time. Therefore, data from continuous air monitoring instruments are integrated in order to provide hourly average concentrations for comparison to respective air quality standards.

The NAAQS averaging times are: 24-hour and annual average for PM_{10}, a 1-hour average for Ozone (O_3) and a 3-hour, 24-hour and annual average for SO_2. Concentrations of PM_{10} averaged over an entire year may be based on daily recordings or on only a more limited number of 24-hour samples. Fig. 6-2 illustrates an example of the differences between real-time, 1-hour, and 4-hour averaging times for gaseous pollutants. Notice that human exposure to gaseous emissions can at times be higher than average recorded levels.

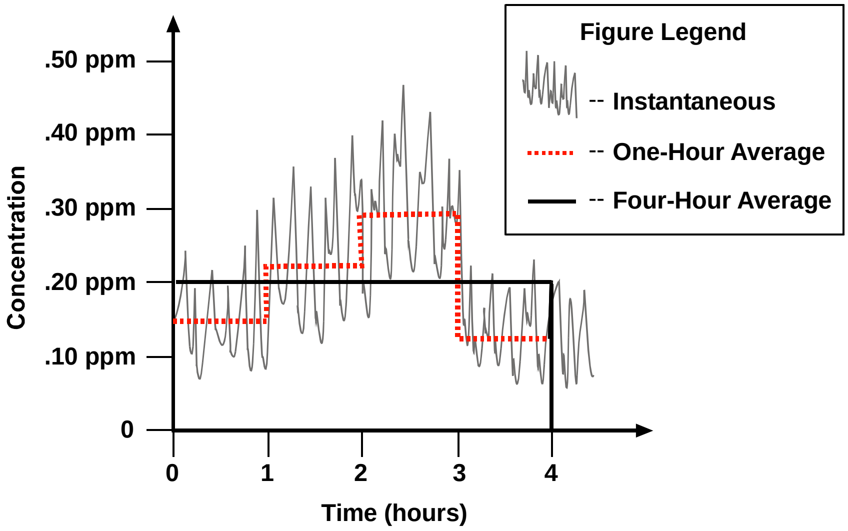


Figure 6-2. Averaging times for gaseous pollutants.

In general, there are ten individual items that need to be addressed in designing an ambient air-monitoring network. These ten items are:

An effective Air Surveillance Monitoring Network is composed of ten operating elements.

1. Set objectives—included in this item is quality of data needed, what air pollutants should be measured, sampling times and seasons of the year sampling will be performed.

2. Choosing the parameters to be measured, in addition to specific pollutants meteorological parameters (i.e., speed, wind direction, temperature and mixing depth) and topographical features, may need to be included.

3. Selecting sampling sites—number and placement based on money and manpower constraints and confidence in the desired results.

4. Scheduling sampling and duration—long term or short term.

5. Selecting air sampling methods—continuous, integrated, grab sampling, intermittent sequential sampling or a combination of these.

6. Equipment selection—identification of suitable instruments, calibration instruments and shelter design and fabrication.

7. Setting calibration procedures—preparation of gas mixtures of known air pollutant concentrations along with instrument flow calibrations.

8. Choosing data recording methods—several methods of recording are available (i.e., strip chart, analog or digital electronic data loggers).

9. Data analysis—useful types of analysis include spatial distribution of pollutants, concentration frequency distribution, averaging time analysis and regression analysis.

10. Reporting results—presented results can be in the form of graphs, histograms, pollution roses and isopleth maps.

In May 1979, EPA promulgated monitoring regulations for the criteria pollutants. The provisions of the regulation, as specified in 40 CFR Part 58 Ambient Air Quality Surveillance, covered the following elements: (1) provided fixed and movable monitoring sites, (2) established uniform standards, (3) required that reference or equivalent methods be used, (4) imposed an annual network review, (5) required public reporting of an air quality index, and (6) required quarterly reports of all national monitoring data and an annual summary report of state and local station data.

U.S. EPA regulation 40 CFR 58 governs Ambient Air Quality Surveillance in order to properly manage monitoring networks.

Four types of air monitoring stations are described in the 40 CFR Part 58 regulations: State and Local Air Monitoring Stations (SLAMS), National Air Monitoring Stations (NAMS), Special Purpose Monitoring Stations (SPMS), and Photochemical Assessment Monitoring Station (PAMS). Each station is designed to serve different data needs and must be established according to specified reporting, siting, and instrumentation requirements.

SLAMS and NAMS represent the majority of all criteria pollutant (SO_2, NO, CO, O_3, Pb, PM2.5, PM10) monitoring across the Nation with over 5000 monitors at approximately 3000 sites. These stations use Federal reference or equivalent methods (FRM/FEM) for direct comparison to the NAAQS. Design and measurement requirements for these networks are codified in the Code of Federal Regulations (CFR) parts 58 (design and quality assurance), 53 (equivalent methods) and 50 (reference methods).

SLAMS consists of a carefully planned network of fixed monitoring stations whose size and distribution is largely determined by the needs of state and local air pollution control agencies to meet their respective SIP requirements. The NAMS are a subset of the SLAMS network with emphasis given to urban and multi-source areas. Essentially, NAMS are the key SLAMS with emphasis on areas of maximum concentration and high population density. NAMS, like SLAMS, must conform to EPA siting criteria and operate according to strict quality assurance procedures that equal or exceed EPA minimum specifications.

A PAMS network is required in each ozone nonattainment area that is designated serious, severe, or extreme. The required networks will have from two to five sites, depending on the population of the area for operation during the summer ozone season. Individual PAMS sites measure ozone precursors, which include approximately 50 volatiles, organic compounds (VOC’s), carbonyl and nitrogen oxides (NO_x) that can react to form ozone. More recent efforts have explored stronger linkage to air toxics monitoring as well as identification or more streamlined PAMS requirements.

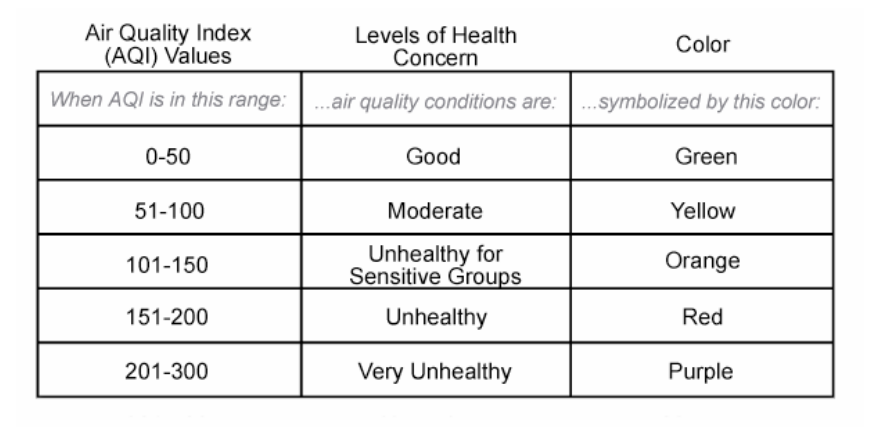
Special Purpose Monitoring Stations (SPMS) provide special studies needed by state and local agencies to support state implementation plans and other air quality program activities. The SPMS are not permanently established and can be adjusted easily to accommodate changing needs and priorities. In addition, the SPMS are used to supplement the fixed monitoring network as circumstances require and resources permit. If the data from

SPMS are used for SIP purposes, they must meet all quality assurance and methodology requirements for SLAMS.

In addition to air monitoring stations methodology and design, the 40 CFR 58 also addresses the reporting requirements of state agencies for the Air Quality Index (AQI). The purpose of the AQI is to help the public understand what measured air concentrations means to their health. To make the AQI easy to understand, EPA has divided the AQI scale, which ranges from 0 to 500, into five categories. Each category has an assigned specific color and corresponds to a different level of health concern. The level of health concern categories and colors are indicated in Table 6-2.

AQI is to help the public understand the meaning of measured air quality categories, such as good (green), moderate (yellow), unhealthy for sensitive groups (orange), unhealthy (red), and very unhealthy (purple). The higher the AQI value, the greater the level of air pollution and the greater the health concern. When AQI values are above 100, air quality is considered to be unhealthy for certain sensitive groups of people. As the value rises above 150, then the air is unhealthy for everyone.

Table 6-2. Air Quality Index Descriptor Chart



Air Quality Index (AQI) Values	Levels of Health Concern	Color
When AQI is in this range:	*...air quality conditions are:*	*...symbolized by this color:*
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151-200	Unhealthy	Red
201-300	Very Unhealthy	Purple

The purpose of the AQI is to help the public understand how measured pollutant concentrations relate to human health affects.

Appendices in 40 CFR 58 also address important issues in relation to the operation on air monitoring networks. The appendices and their titles are as follows:

1. Appendix A: QA Requirements for SLAMS
2. Appendix B: QA Requirements for PSD Air Monitoring
3. Appendix C: Ambient Air Quality Monitoring Networks
4. Appendix D: Network Design for SLAMS and NAMS
5. Appendix E: Probe Siting Criteria
6. Appendix F: Annual SLAMS Air Quality Information
7. Appendix G: AQI and Daily Reporting

The network should be designed to meet one of six basic objectives: (1) to determine highest concentrations expected to occur in the area covered by the network; (2) to determine representative concentrations in area of high population density; (3) to determine the impact on ambient pollution levels of significant sources or source categories; (4) to determine general background concentration levels; (5) to determine the extent of regional pollutant transport among populated areas, and in support of secondary standards; and (6) to determine the welfare-related impacts in more rural areas (such as visibility impairment and effects on vegetation.

Air monitoring networks are designed to measure highest concentrations, representative concentrations, their impact on human health and welfare, and their composition.

These six objectives indicate the nature of the samples that the monitoring network will collect, which must be representative of the spatial area being studied. The goal in siting monitoring stations is to correctly match the spatial scale represented by the sample of monitored air with the spatial scale most appropriate for the monitoring objective of the station. The spatial scale of representativeness is described by physical dimensions of the air parcel nearest to a monitoring station throughout which actual pollution concentrations are reasonably similar.

Appendix D of 40 CFR part 58 provides guidance concerning the concept of spatial scales of representativeness that individual stations in a SLAMS network should represent. Ideally, the monitor should be located such that the air quality of the volume of sampled air be representative of the air quality over the entire area that the monitoring station is intended to represent. For most ambient monitoring objectives, the scale of representativeness of most interest are: microscale (1-100 meters), middle scale (100m-0.5 kilometers), neighborhood scale (0.5-4.0 kilometers), urban scale (4-50 kilometers), regional scale (tens to hundreds of kilometers) and national and global scales (nation and globe as a whole). During the station selection process, the goal is to match the spatial scale represented by the sample of monitored air at a given location with the spatial scale most appropriate for the monitoring objective of that respective station. Table 6-3 shows the relationship among monitoring objectives and scales of representativeness.

Table 6-3. Relationship Among Monitoring Objectives and Scale Representativeness

Monitoring Objectives	Appropriate Siting Scales
Highest Concentration	Micro, middle, neighborhood, or urban
Population	Neighborhood, urban
Source Impact	Micro, middle, neighborhood
General/Background	Neighborhood, urban, regional
Regional Transport	Urban/regional
Welfare-related Impacts	Urban/regional

For example, for SO_2 monitoring, a neighborhood scale station applies to areas where the SO_2 concentration gradient is relatively flat, mainly suburban areas surrounding the urban center or in large sections of small cities and towns. Table 6-4 shows a summary of spatial scales applicable for SLAMS and required for NAMS for each pollutant.

Table 6-4. Summary of Spatial Scales Applicable for SLAMS and Required for NAMS for Each Criteria Pollutant

Scales Applicable for SLAMS							
Spatial Scale	*SO_2*	*CO*	*O_3*	*NO_2*	*Pb*	*PM_{10}*	*$PM_{2.5}$*
Micro	X	X			X	X	X
Middle	X	X	X	X	X	X	X
Neighborhood		X	X	X	X	X	X
Urban	X		X	X	X	X	X
Regional	X		X		X	X	X
Scales Applicable for NAMS							
Micro	X	X			X	X	X
Middle		X			X	X	X
Neighborhood	X	X	X	X	X	X	X
Urban			X	X			
Regional							X

In addition, information on Appendices in 40 CFR 58, network design, siting guidance and other guidance documents can be found on the Air Monitoring Technical Information Center (AMTIC) web site, located at http://www.epa.gov/ttn/amtic/. In order to assure the quality of data from air monitoring measurements, two distinct and important interrelated functions must be performed. One function is the control of the measurement process through broad quality assurance activities, such as establishing policies and procedures, developing data, quality objectives, assigning roles and responsibilities, conducting oversight and reviews, and implementing corrective actions. The other function is the control of the measurement process through the implementation of specific quality control procedures, such as audits, calibrations, checks, routine self-assessments, etc.

In general, the greater the control of a given monitoring system, the better will be the resulting quality of the monitoring data. Elements of a quality assurance (QA) program include: preventative maintenance, sample collection, sample analysis, calibration, corrective action, document control and revision, quality planning, training, inter/intra lab testing, audit procedures, data validation reliability reports, QA manuals and QA plans.

In 1999, the EPA convened a “National Monitoring Strategy Committee” (NMSC), comprised of representatives from EPA, State and local agencies, and Tribes to begin a process for taking a holistic review of our Nation's air monitoring networks and making recommendations for improving network design. The proposed strategy is a new approach to the Nation's air monitoring programs. The overarching goal of the Strategy is "to improve the scientific and technical competency of existing air monitoring networks so as to be more responsive to the public, and the scientific and health communities, in a flexible way that accommodates future needs in an optimized resource constrained environment."

There are six essential components to the objectives:

- A network design proposal referred to as the *National Core Network (NCore)* for national air monitoring networks that increases integrated multi- pollutant monitoring and facilitates the timely delivery of data, using state-of-the-art information technology systems, to the public and scientific communities.
- *Technical assessments* of the existing air monitoring networks that probe into the actual program support value of air quality data by considering factors such as monitoring site redundancy, relative concentration values, operational logistics and relevancy to current priorities.
- A *restructuring* of existing *monitoring regulations* to remove any obstacles that may impede progress and to accommodate current and forthcoming needs.
- A *revised national quality assurance* program focused on a performance based measurement system to meet multiple monitoring objectives.
- Proposals to *enhance* technical methods in air monitoring networks focused on *continuously operating particulate matter and information transfer technologies.*
- A *communications and outreach* effort to explain the rationale and benefits of this strategy to all stakeholders.

These components collectively act (and interact) to promote changes in the existing network infrastructure (see Figure 6-3).

NCore is the key component of the new ambient air monitoring strategy, which accounts for the air monitoring issues and concerns listed in the preceding six objectives. NCore provides an opportunity to address new directions in monitoring and begin to fill measurement and technological gaps that have accumulated in the networks. The strategy recognizes that there are both nationally and locally oriented objectives in air monitoring that require different design approaches, despite our best attempts at leveraging resources and maximizing versatility of monitoring stations. NCore takes a more proactive approach at addressing national level needs that often have to make the most of available data sources, regardless of their design basis. NCore introduces a new multi-pollutant monitoring component, and addresses the following major objectives:

- Provide timely reporting of data to public by supporting AIRNow, air quality forecasting and other public reporting mechanisms.

- Support the development of emission strategies through air quality model evaluation and other observational methods.

- Support long-term health assessments that contribute to ongoing review of National Ambient Air Quality Standards.

- Evaluate compliance with NAAQS through better establishment of nonattainment/attainment areas.

- Support scientific studies ranging across technological, health, and atmospheric process disciplines.

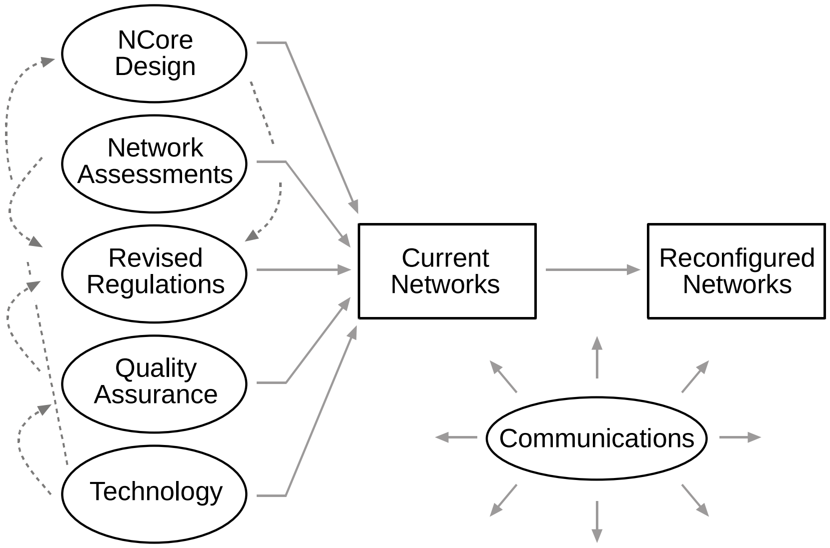


Figure 6-3. Information Flow Across Monitoring Strategy Components

NCore is structured as a three-tiered approach, Levels 1-3 (Figure 6-4) based on measurement complexity, with Level 1 being the most sophisticated, and Level 3 being the least. Level 1 “master” sites would serve a strong science and technology transfer role for the network, an important component of health and epidemiological studies and be viewed as a continuation of the current PM2.5 “supersite” program, which has finite duration. It is estimated that 3 to 10 such sites nationally would serve this purpose. The Level 2 sites would be the “backbone” of NCore, with approximately 75 such sites nationally. These sites would add a new multiple pollutant component to the networks with a minimum set of continuously operating instruments that, in many areas, would benefit from placement at existing PM speciation, PAMS or air toxics trends sites. Level 3 sites are largely single-pollutant sites, emphasizing the need for spatially rich network primarily for the most ubiquitous criteria pollutants, PM2.5 and ozone, and addressing an assortment of compliance related needs. Progressing through Levels 1 through 3, the character of these sites moves from a strong science orientation toward compliance.

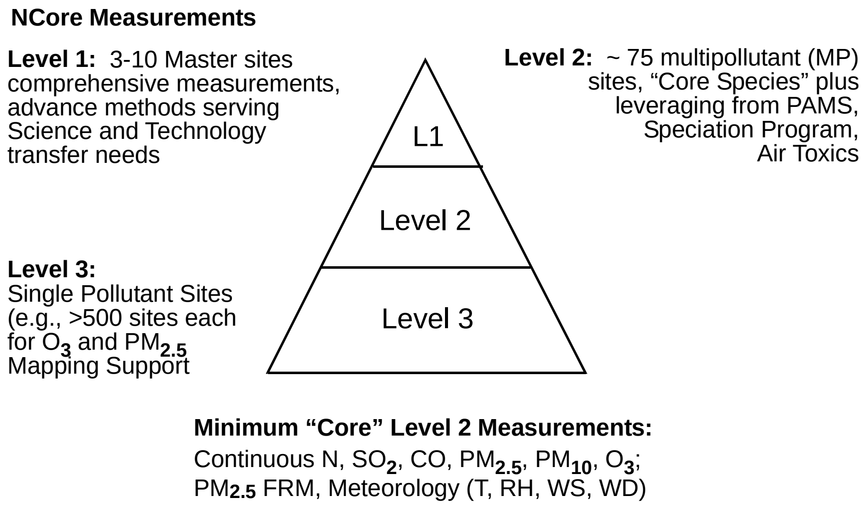


Figure 6-4. Components of NCore

The National Ambient Air Monitoring Strategy Revised Draft Document and Summary Document can be found on the Air Monitoring Technical Information Center (AMTIC) web site, located at http://www.epa.gov/ttn/amtic/.

The Clean Air Act authorized programs such as the National Visibility Program, PSD, and IMPROVE to monitor and improve visual air quality.

The Clean Air Act authorizes EPA to protect visibility, or visual air quality, through a number of programs. These programs include the National Visibility Program, the Prevention of Significant Deterioration (PSD) Program for the review of potential impacts from new and modified sources, the secondary National Ambient Air Quality Standards for PM_{10} and $PM_{2.5}$, and under the provisions of acid rain deposition. Visibility impairment occurs as a result of the scattering and absorption of light by particles and gases in the atmosphere. It is most simply described as the haze that obscures the clarity, color, texture, and form of what we see. The same particles linked to serious health and environmental effects (sulfates, nitrates, organic carbon, elemental carbon [soot], and crustal material) can also significantly affect our ability to see (see Figure 6-5).

Both primary emissions and secondary formation of particles contribute to visibility impairment. Primary particles, such as elemental carbon from diesel and wood combustion or dust from certain industrial activities or natural sources, are emitted directly into the atmosphere. Secondary particles that are formed in the atmosphere from primary gaseous emission include sulfate from sulfur dioxide (SO_2) emissions, nitrates from nitrogen oxide (NOx) emissions, and organic carbon particles formed from condensed hydrocarbon emissions.

In 1987, the Interagency Monitoring of Protected Visual Environments (IMPROVE) visibility network was established as a cooperative effort between EPA, the National Oceanic and Atmospheric Administration, the National Park Service, the Bureau of Land Management, the U.S. Fish & Wildlife Services, and state governments. The objectives of the network are to establish current conditions, to track progress toward the national visibility goal by documenting long-term trends, and to provide information for determining the types of pollutants and sources primarily responsible for visibility impairment. Chemical analysis of aerosol measurements provides ambient concentrations and associated light extinctions for PM_{10}, $PM_{2.5}$, sulfates, nitrates, organic and elemental carbon, crustal material, and a number of other elements. The IMPROVE program has established protocols for aerosol, optical, and photographic monitoring methods, and employs these methods at more than 70 sites.

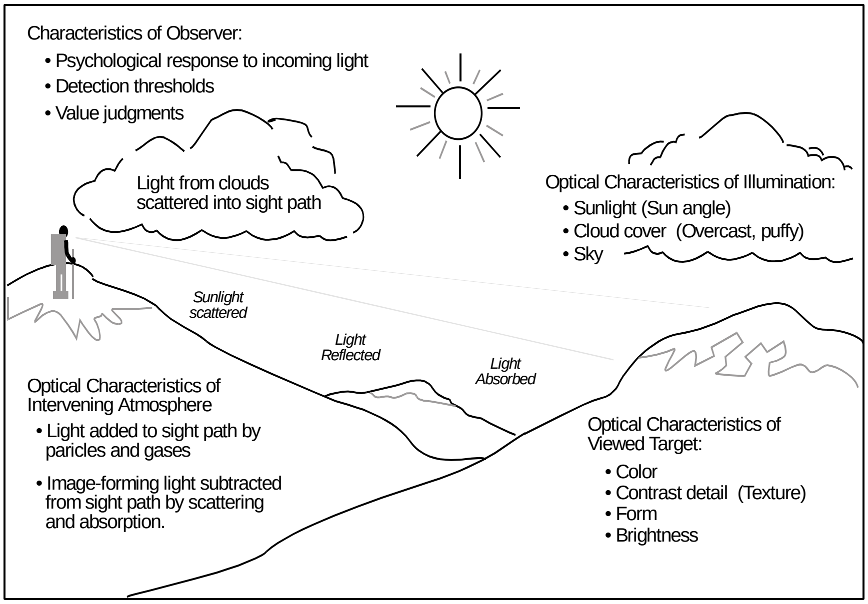


Figure 6-5. Properties of the Atmosphere

Clean Air Status and Trends Network (CASTNET)

CASTNET was originally designed to account for progress of strategies targeting major electrical generating utilities throughout the Midwest, which release acid rain precursor emissions, sulfur, and nitrogen oxides. CASTNET was deployed in the 1980s as part of EPA's National Acid.

Precipitation Assessment Program (NAPAP). An assessment of the network in the mid-1990s, lead to a more optimized and less extensive network. Network operations are contracted out to private firms funded through Science and Technology (S&T) funds and managed by EPA's Office of Air and Radiation. CASTNET consists of approximately 70 sites located predominantly throughout the East with the greatest site densities in States along the Ohio River Valley and central Appalachian Mountains. (Figure 6-6.). Two week aggregate samples are collected by filter packs and analyzed for major sulfur and nitrogen oxide transformation compounds (i.e., end products such as sulfate and nitrate ions).

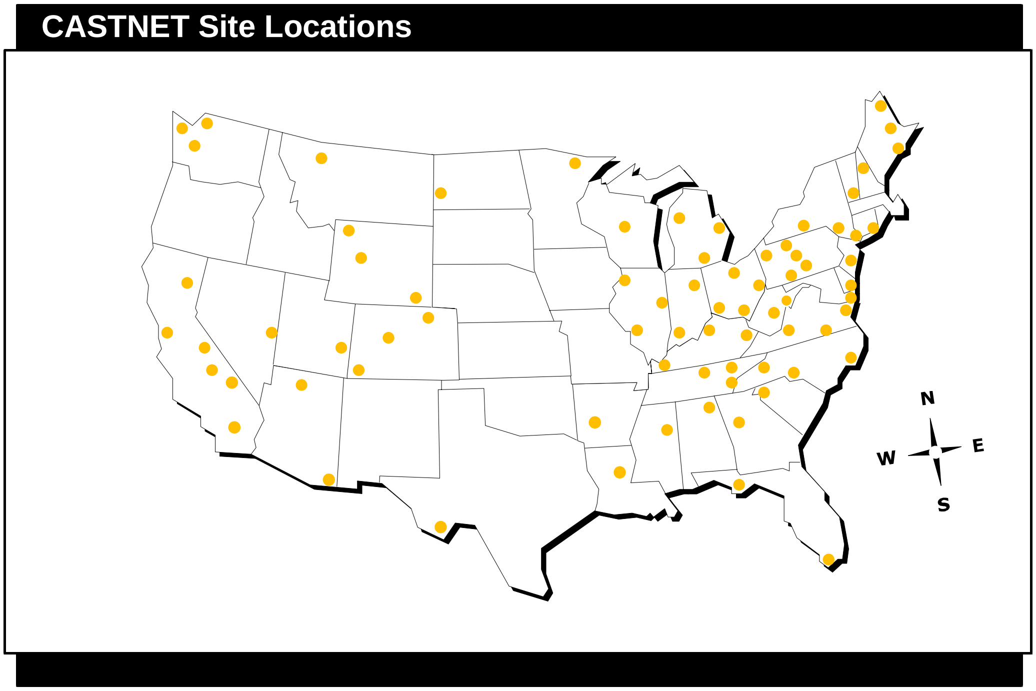


Figure 6-6. Clean Air Status and Trends Network (CASTNET) Site Locations

Hazardous Air Pollutants (HAPs)

Hazardous substances not formally identified as criteria pollutants are considered non-criteria pollutants and are categorized under National Emissions Standards for Hazardous Air Pollutants (NESHAPs) or Hazardous Air Pollutants (HAPs) regulations. Hazardous air pollutants or toxic air pollutants are pollutants known to cause or are suspected of causing cancer or other serious human health effects, or ecosystem damage. Hazardous air pollutants are emitted from literally thousands of sources including large stationary industrial facilities or major point sources (such as electric power plants or utilities), smaller area sources (such as dry cleaners), and mobile sources (such as automobiles).

Hazardous air pollutants (HAPs) are pollutants known to cause or suspected of causing cancer or other serious human health or welfare effect.

Understanding the potential health risk of these pollutants, Congress responded with amendments to the Clean Air Act of 1990. These amendments established a new approach for regulating hazardous air pollutants (HAPs). In revising the Clean Air Act, Congress specifically listed 189 compounds as hazardous air pollutants. The U.S. EPA has been directed to develop technologically based emissions standards for all these pollutants. This list includes all pollutants that are known or suspected to cause cancer and other adverse health effects.

The CAA Amendments categorized pollutants and identified 189 compounds for regulation. This list of HAPs includes substances such as carbon tetrachloride, chlorine, ethylene oxide, cadmium, and manganese, with the majority of the 188 HAPs being volatile organic compounds. The new approach to regulating HAPs is divided into two phases. The first requires the development of technology-based emissions standards for stationary sources of the 188 HAPs. The second phase is to evaluate remaining problems or risks and develop additional regulations to address sources of those problems, as required. This National Air Toxics Program approach will progress from the more regulatory technologically based approach to a more risk-based approach. This will require more and better information about all emission sources of HAPs, ambient levels of HAPs, and human and eco-system exposure to HAPs.

CAA Amendments identified 189 HAP compounds; the National Air Toxics Program is responsible for managing these toxins.

The success of the National Air Toxics Program will critically depend on the ability to quantify the impacts of air toxics emissions on public health and the environment. To that end, EPA has initiated numerous National Air Toxics Assessment (NATA) activities to help identify areas of concern, characterize risks, and track progress. Ambient air monitoring is another important component of NATA. Ambient measurements are useful to characterize ambient concentrations and deposition in representative areas, provide data to support and evaluate dispersion and deposition models, and establish trends and evaluate the effectiveness of HAP reduction strategies. There are approximately 300 monitoring sites currently producing ambient data on hazardous air pollutants.

EPA is working with state and local air monitoring agencies to develop a monitoring network that is representative of air toxics problems on a national scale and which provides a means to obtain data on a more localized basis. The network will eventually represent an integration of information from many monitoring programs, including PAMS, which provides information on VOCs and aldehydes, the new urban $PM_{2.5}$ chemical speciation, and rural IMPROVE networks, which provide information on HAP trace metals.

Several states have long-standing air toxics monitoring programs that produce measurements on a multitude of HAPs, including important urban HAPs. Some of these state programs are assisted by EPA contractor-supported Urban Air Toxics Monitoring Program (UATMP), as well as the Non-Methane Organic Compound (NMOC) and Speciated Non-Methane Organic Compound (SNMOC) monitoring program. The UATMP is dedicated to toxics monitoring, which involves measurements of 39 HAP VOCs and 13 carbonyl compounds. PAMS also measure HAPs among the many pollutants that are precursors of ozone. The PAMS program requires routine year-round measurement of VOCs, which include nine HAPs: acetaldehyde, n-hexane, styrene, toluene, xylene,(m/p-xylene, o-xylene) and 2,2,4-trimethlypentane.

The Fourier Transform Infrared (FT-IR) Monitoring system is one of the new innovations designed to simultaneously measure multiple organic compounds in the ambient air.

Measurement of organic pollutants, which include many HAPs, in ambient air is often difficult, in part because of the variety of organic substances of potential concern, and the lack of standardized and documented methods. Of the 188 HAPs listed in Title III, Section 112, of the CAA, 99 are volatile organic compounds, 50 are semi-volatile organic compounds, 11 are complex organic mixtures and 28 are nonvolatile inorganic compounds. In order to address this need to characterize ambient concentrations of HAPs, EPA – through the National Risk Management Research Laboratory (NRMRL) – has developed a updated Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air to assist in developing and maintaining necessary up-to-date monitoring technology for these pollutants. The Compendium contains a set of 17 (Methods TO 1- 17) peer reviewed, standardized methods for determining volatile, semi-volatile, and selected toxic organic pollutants in the air.

The updated compendium methods, such as TO-16 have incorporated newer technology like the long-path open-path Fourier Transform Infrared (FT-IR) Monitoring systems that are potentially capable of simultaneously measuring multiple organic compounds in the ambient air. In addition, EPA has also compiled a Compendium of Methods for determining inorganics. Both compendiums are available on the AMTIC web site.

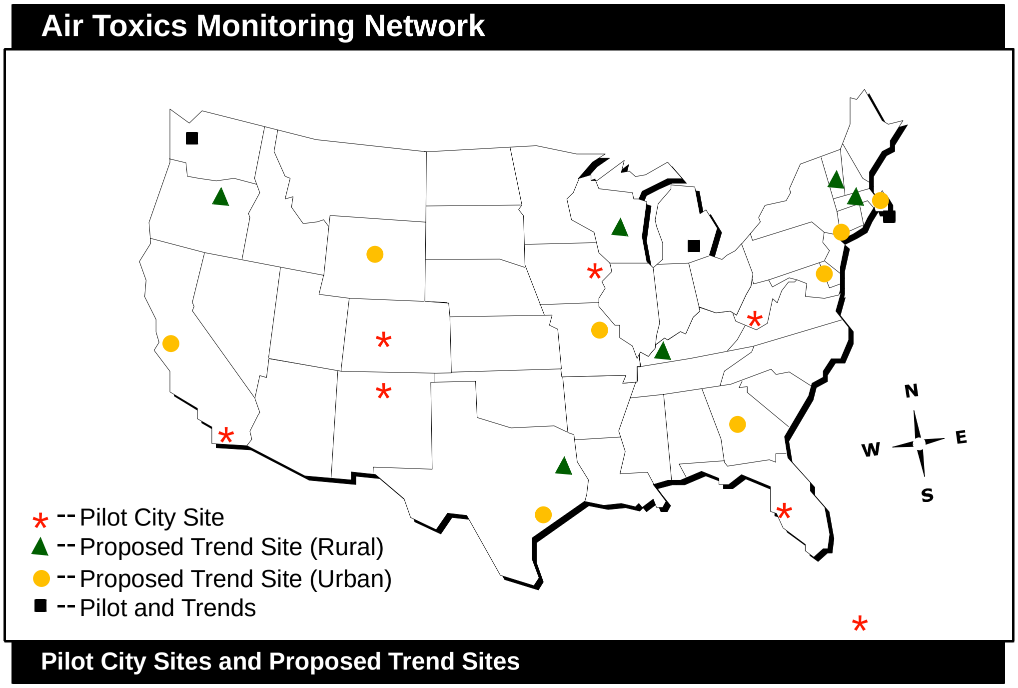


Figure 6-7. Air Toxics Pilot City Sites and Proposed Trend Site Locations

NAME ______________________________________ DATE _______________ SCORE________

CHAPTER 6 AMBIENT AIR QUALITY MONITORING

Multiple Choice

Directions: *Read each question and choose the best answer. Write the letter of your answer in the space provided.*

1. The federal regulation that governs Ambient Air Quality Surveillance methods is _______.

a. 40 CFR 50
b. 30 CFR 71
c. 40 CFR 53
d. 50 CFR 25
e. 40 CFR 58

1. ________

2. The purpose of an ambient air quality monitoring program include all of the following, **except** _______.

a. to determine compliance with standards
b. to activate emergency control procedures
c. to develop long-term control strategies
d. to establish air quality control regions (AQCRs)
e. to observe pollution trends

2. ________

3. Which of the following substances is **not** a federally regulated criteria pollutant?

a. SO_2
b. NO_2
c. VOCs
d. O_3
e. CO

3. ________

4. Each of the following is an example of an ambient air quality monitoring station, **except _______.**

a. State and Local Air Monitoring Stations (SLAMS)
b. Regional Air Monitoring Stations (RAMS)
c. National Air Monitoring Stations (NAMS)
d. Special Purpose Monitoring Stations (SPMS)
e. Photochemical Assessment Monitoring Stations (PAMS)

4. ________

5. Which of the following is **not** an element of an effective quality assurance and quality control program?

a. Preventative Maintenance
b. Sample Collection
c. Sample Analysis
d. Data Reporting
e. Compliance and Enforcement

5. ________

6. The most commonly used non-continuous method of gas collection and sampling is through the use of ________.

a. bubblers or impingers
b. electrostatic precipitation
c. impaction
d. filtration
e. gravitational settling

6. ________

7. A technique used to collect and sample particulate matter is ________.

a. cryogenic analysis
b. absorption
c. adsorption
d. condensation
e. filtration

7. ________

8. A device used to sample particulate matter in which pollutants are drawn through a glass fiber filter using a vacuum motor to draw the air is a ________.

a. electrostatic precipitator
b. Hi-vol. sampler
c. paper tape sampler
d. surface condenser
e. Venturi scrubber

8. ________

9. A sampling technique used to collect ambient air gases with a collection tube containing solid surfaces such as carbon, silica gel or molecular sieves is called ________.

a. filtration
b. adsorption
c. condensation
d. impaction
e. absorption

9. ________

10. A principle of particulate matter collection and sampling in which particles are drawn through a device, but deflected from their original path is called _______.

a. filtration
b. electrostatic precipitation
c. gravitational settling
d. impaction
e. thermostatic precipitation

10. ______

Matching

Directions: Match each sampling technique with the proper description.

Sampling Techniques

A. Static sampling
B. Grab sampling
C. Intermittent sampling
D. Continuous sampling
E. Absorption
F. Adsorption

________ **11.** The preferred method of sampling particulate matter and acid rain in which contaminants are collected on a periodic basis, typically over longer averaging times (i.e., 24 hours).

________ **12.** Collection of contaminants by diffusion of gas, sedimentation of particles, or impaction on a sticky surface.

________ **13.** The preferred method of sampling used by monitoring programs to obtain real-time sampling averages of contaminants.

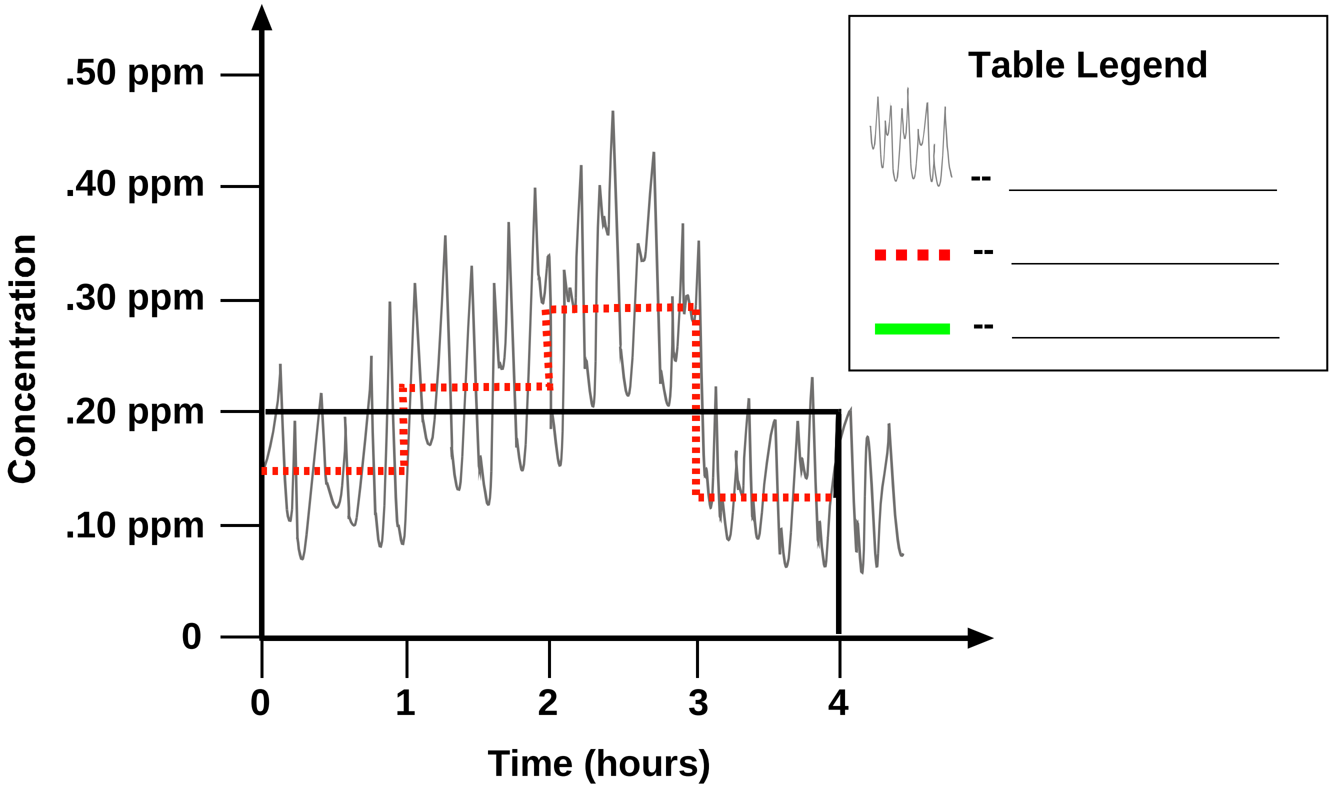
________ **14.** A sampling method used to collect organic gases on a solid surface such as carbon, silica gel, or a molecular sieve.

________ **15.** A method of collection in which a small volume of air is quickly captured in an evacuated bottle, gas syringe, or synthetic bag.

________ **16.** A sampling technique in which gas is drawn through a liquid reagent and removed from the air stream as it becomes dissolved into the liquid.

Averaging Times for Gaseous Pollutants

Directions: *Review the gaseous monitoring report below and answer the questions in the space provided.*



(Source: Godish, Thad, *Air Quality*, 3rd Edition, Lewis: New York, 1997, p. 218.)

Real-time air quality monitoring instruments widely used in the past two decades provide a continuous record of fluctuating pollutant concentrations. Averaging times and concentrations are easily extrapolated from continuous monitoring activities.

17. Complete the table legend in the space provided.

18. What is the 3-hour NAAQS for SO$_2$? _________ According to the gaseous sample above, is this location in compliance for SO$_2$? ________

19. What is the 1-hour NAAQS for CO? _________ According to the gaseous sample above, is this location in compliance for CO? ________

20. What is the 4-hour average for the gaseous sample above? ___________________

21. What is the total concentration of the gas after the second hour of sampling? ___________________

Table Interpretation

Directions: *Review the National Ambient Air Quality Standards (NAAQS) table shown below. Fill in the missing information. (2 points)*

Pollutant	Averaging Time	Primary Standard	Secondary Standard
Carbon Monoxide (CO)	**22.**	10 mg/m^3 (9 ppm)	**23.**
Nitrogen Dioxide (NO^2)	**24.**	100 μg/m^3 (0.053 ppm)	same
25.	Annual Arith. Average	80 μg/m^3 (0.03 ppm)	none
	24-hour	365 μg/m^3 (0.14 ppm)	none
	26.	none	**27.**
PM$_{10}$ ($\leq$ 10μm)	**28.**	50 μg/m^3	**29.**
	24-hour	**30.**	
PM$_{2.5}$ ($\leq$ 2.5μm)	Annual Arithmetic Mean	**31.**	same
	32.	65 μg/m^3	
Ozone (O$_3$)	**33.**	157 μg/m^3 (0.8 ppm)	same
34.	3 month average	**35.**	same

36. Explain the difference between the primary and secondary standards used to control national pollutant levels.

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	E	6-13
2.	D	6-3
3.	C	6-4
4.	B	6-12
5.	E	6-15
6.	A	6-9
7.	E	6-7
8.	B	6-8
9.	B	6-9
10.	D	6-7
11.	C	
12.	A	
13.	D	
14.	F, E	
15.	B	
16.	E	
17.	Continuous Sampling, One Hour Average, Four Hour Average	6-11
18.	.5 ppm and Yes	
19.	35 ppm and Yes	
20.	.20 ppm (400 $\mu g/m^3$)	
21.	.30 ppm (600 $\mu g/m^3$)	
22-35.	See table on page 6-5	
36.	Primary ambient air quality standards represent the maximum levels of pollution to which a person may be exposed without incurring any health risks or side effects. Secondary standards represent the maximum levels that a pollutant may be present over an extended period of time. Generally, the averaging times are greater for secondary standards.	

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CHAPTER 7

Measurement of Pollutant Emissions

Lesson Goal

Demonstrate an understanding of the Federal Test Methods and continuous emission monitoring systems by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Discuss the importance of measuring emissions from stationary sources.
2. Describe the principles behind source testing and continuous emission monitoring.
3. Explain what Federal Test Methods are and where they may be found.
4. Recognize the procedures necessary for manual sampling from the exhaust stack of an industrial source.
5. Explain the purpose of manual and continuous monitoring and the uses of the data obtained.
6. Relate the uses of Reference Methods 1-4 to the other Reference Methods.
7. Explain how Reference Methods 5 and 6 are conducted.
8. List the factors that influence particulate sampling.
9. Distinguish between *extractive* and *in-situ* continuous emission monitoring systems.
10. Describe how sampling differs from air quality monitoring.

Recommended Reading: Godish, Thad, “Air Quality and Emissions Assessment,” *Air Quality*, 3rd Edition, New York: Lewis, 1997, pp. 215-236.

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Measurement of Pollutant Emissions

Air pollution control programs require the curtailment of contaminants being released into the atmosphere as a result of everyday human activity. The measurement of both the type and quantity of these contaminants is an important part of obtaining the necessary data needed to implement a meaningful control program. The process of monitoring particulate and gaseous emissions from a stationary source is often referred to as *source sampling* or *source testing*.

Source sampling can be used not only to protect society from dangerous pollutant emissions, but can also be used to improve the operational efficiency of industrial systems.

Testing the effluents from stationary sources is of a prime practical importance. Results of source tests are one of the single most important types of technical information generated whether for agency or industry use. Source testing is an invaluable touchstone for judging the relative importance of a given sources' contribution of pollutants. Testing the gas stream entering and leaving a pollution control device provides the assessment necessary to determine whether it is efficiently reducing pollution.

The analysis of effluent gases from industrial systems, such as boilers and incinerators, also provides important feedback for "tuning" them to increase operational efficiency, conserve fuel, or process materials and decrease pollutant emissions. The results are a yardstick for measuring the progress of a control program, an engineering tool to be used in the design and tuning of control methods, and also as a legal tool in the case of a violation of an air pollution control regulation. In fact, regulation must be supported and enforced by an objective means of assessing whether emission limits have been met. Clearly emissions measurement plays a valuable role in controlling air pollution.

The purpose of source sampling or testing is to obtain reliable and representative data about atmospheric pollutants.

Regardless of the uses for the information, the immediate objective in testing a source of air pollution is to obtain reliable and representative data about the composition of the effluent and its rate of emission into the atmosphere. Every source test has the same basic requirements:

1. The gas being sampled from a source should represent either the total or a known portion of the emissions from the source.
2. Samples of the emissions collected for analysis must be representative of the gas stream being sampled.
3. The volume of the gas sample withdrawn for analysis must be measured accurately in order to calculate the concentration of the analyzed constituents in the sampled gas stream.
4. The gas flow rate from the source must be determined in order to calculate emission rates for the various constituents.

Although source-testing methods, like the Performance Test Code 21-1941 of the American Society of Mechanical Engineers, have existed since the 1940s, the methods were not always mandatory and had wider interpretations of parameters and standard calculations.

Federal Reference Methods were first promulgated in 1971, originally composed of eight measurement methods.

The original U.S. EPA Reference Methods (FRM) 1 through 8, first promulgated in 1971, were “wet chemistry” methods applied to sampling and analyzing particulate matter, and nitrogen oxides. These methods were the result of the first New Source Performance Standards (NSPS) authorized by Congress in the Clean Air Act of 1970, codified in Section 111 of the Act, and promulgated in December of 1971.

In order to determine whether the specific NSPS emission limitations were being met, representative, valid and standardized testing methods were needed to measure emissions. The EPA’s first set of NSPS standards focused on source categories that emitted large quantities of pollutants, such as utility boilers, incinerators, Portland cement plants, nitric acid plants and sulfuric acid plants; therefore, the original measurement methods reflect the criteria pollutant emissions characteristics of those sources.

Subsequent Reference Methods also reflect the emission types and characteristics of the additional promulgated NSPS source categories. The same logic applies to continuous emission monitoring (CEM) covered by Performance Specifications (PS) that has become part of NSPS requirements. The FRMs and PSs are now used almost universally for both new and existing source testing and serve as the standards for compliance testing.

Source testing methods are also promulgated for some hazardous pollutants that were regulated prior to 1991 under the National Standards for Hazardous Air Pollutants (NESHAPs) program; for existing sources regulated under a State Implementation Plan (SIP), which each state must develop; and for the Maximum Achievable Control Technology (MACT) standards for hazardous air pollutant source categories that were promulgated after 1990. The Emission Measurement Center in the Office of Air Quality Planning and Standards (OAQPS) developed the methods numbering system for the source test methods for air emissions that are found in the Code of Federal Regulations (CFR). Methods numbers or Performance Specifications between 1 and 100 are for NSPSs and are found in 40 CFR Part 60, Appendix A. Method numbers in the 100 series are for the NESHAPs. These methods are found in 40 CFR Part 61, Appendix B. Methods in the 200 series are example methods that can be used by the states in their SIPs. The 200 series methods are found in 40 CFR Part 51, Appendix M, while the 300 series methods are for the MACT standards that can be found in 40 CFR Part 63, Appendix A. In addition, all of these methods can be found on the Emission Measurement Center's Web site at http://www.epa.gov/ttn/emc.

Source Sampling Methodology

Stationary source emissions occur primarily as either a gas or solid. The ability to collect a representative sample of particulate or gaseous pollutants largely determines the success of the measurement. Since no single method of measurement can accurately analyze every form of pollutant emitted from an exhaust stack, it is important to understand the properties of particulate and gaseous pollutants and the methods used to measure them.

Federal Reference Methods specify the procedures and equipment necessary to perform source sampling.

The U.S. E.P.A. Reference Methods specify the procedures and equipment necessary for measuring the various constituents of effluent gas from stationary sources. The methods also include complete descriptions of principles, applicability, and specific formulas needed to calculate the test results in standard units. Each source test can be thought of as an original scientific study and must be executed with care as in performing any scientific study.

Each Federal Reference Method governs the procedures, equipment, and sampling of source emissions:

FRM 1 – Point Locations
FRM 2 – Gas Flow Rate
FRM 3 – Gas Molecular Weight
FRM 4 – Gas Moisture Content
FRM 5 – Particulate Matter
FRM 6 – Sulfur Dioxide
FRM 7 – Nitrogen Oxides
FRM 8 – Sulfuric Acid Mist

However, each individual source test is somewhat different. Sampling situations can range from studies that are hot, wet, and dirty to those at ambient temperatures with very little moisture and particulate matter.

As a result of realities like these, the source test methods have been developed in order that samples can be obtained in a short period of time, at relatively reasonable costs, without sacrificing technical viability. The Courts have repeatedly upheld the results from emissions of stationary sources. In fact, they have become the definitive tool for evaluating industrial compliance with, or violation of, stationary source emission limits. Not only did the methods prove to be reliable across sources, but also have also withstood the test of time and scrutiny and are still used today. For example, most states rely upon either U.S. EPA Reference Methods or similar, more stringent methods that meet the approval of the U.S. EPA for compliance testing.

While Methods 5, 6, 7, and 8 are concerned directly with the capture and measurement of specific pollutants in a gas stream, Methods 1, 2, 3, and 4 are concerned with characterizing other aspects of the gas stream. In this respect, the first four methods are supportive, supplying information necessary to perform other methods or calculate their results. Method 1 is unique among these methods because it is concerned with assessing the suitability of the sampling site and determining the array of sampling points.

Because the original eight methods are the foundation for subsequent methods, it is important to look at some of their major elements in greater detail.

1. **Distributed Sampling Points.** A representative sample of the effluent is taken by first measuring the velocity, as shown in Figure 7-1, then extracting gas from an array of sampling points distributed over equal areas of the cross section of the stack or duct. If only gaseous pollutants are to be sampled, less sampling points are required since the stack gases are considered sufficiently mixed.

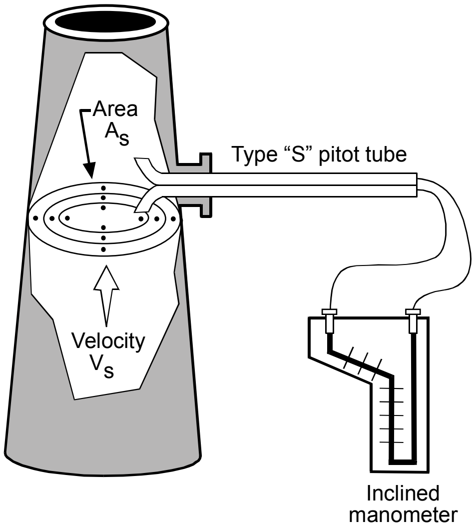


Figure 7-1. Representative Point Selections

2. **Sampling Distributed Over Time.** Each point should be sampled for an equal period of time, with the total sampling time or run usually lasting about an hour. Typically, three runs are performed after which their results are then averaged.

3. **Isokinetic Sampling.** When sampling for particles it is essential that the sample be extracted at the same rate at which the gas is flowing through the stack or duct. The stack gas velocity is measured at each individual sample point and the sample extraction rate is adjusted to withdraw the sample at the same rate as the sampled points velocity. This kind of sampling is called *isokinetic* sampling and is meant to ensure that a representative sample, equal in concentration to the stack, is extracted from the gas stream (see Figure 7-2). If the sample is isokinetic, the distribution of particles sizes (from small to large) entering the probe will be exactly the same as that in the stack gas itself. Thus, the particulate sample will be representative of the stack gas particle size distribution (see Figure 7-3). This is the ultimate goal of isokinetic sampling is to obtain a representative sample.

Isokinetic sampling occurs when the sampling device extracts the stack gas at a velocity equal to the gas stream at each sample point.

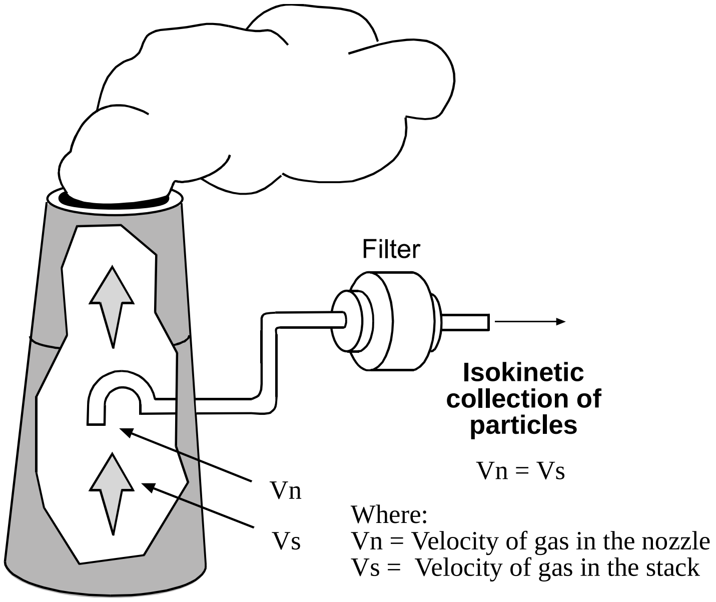


Figure 7-2. Isokinetic Sampling of Particles From a Stack

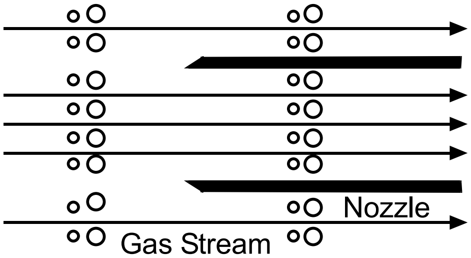


Figure 7-3. Isokinetic Conditions

If the sample rate V_n is too low or too high with respect to the stack gas velocity V_s, the sampling is said to be anisokinetic and errors may result in the particulate concentration measurements. When the sampling is not isokinetic, problems develop in the region of the curved streamlines near the nozzle inlet. When the nozzle inlet velocity is greater than the stack velocity (over isokinetic), the nozzle brings in gas from regions not directly in front of it. Gas streamlines converge at the nozzle inlet to bring in a volume of gas greater than that obtained for acceptable isokinetic conditions. When over isokinetic sampling occurs (see Figure 7-4), the large particles, because of their inertia, do not follow the streamlines, but break through them to continue in the same direction.

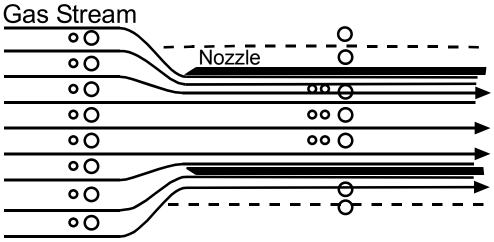


Figure 7-4. Over Isokinetic Conditions

Small particles will follow gas streamlines, and a non-representative number of small particles will be present in the sample gas volume. The measured particulate concentration will be lower than that at an exact (100%) isokinetic condition, due to the dilution of the sample by the additional volume of stack gas and the sample is biases with small particles.

When the nozzle inlet velocity is less than the stack velocity, the nozzle is extracting the gas at too low a rate. The gas streamlines bunch up at the nozzle, almost as if it were an obstruction. A smaller volume of stack gas is being extracted into the nozzle. However, the large particles in the gas stream still pass through the compacted streamlines near the nozzle and flow into it due to their inertia. The sample is biased with large particles and the particulate concentration is higher, than at an exact (100%) isokinetic condition, due to the smaller volume of stack gas that was extracted. This condition is referred to as under isokinetic and is depicted in Figure 7-5.

Another problem that can occur is, although the sampling is being extracted isokinetically, the nozzle may be misaligned. Here, the streamlines bend into the nozzle inlet, but the large particles are not able to make the turn. These large particles will therefore not be included in the sample and the resultant particulate concentration will be too low.

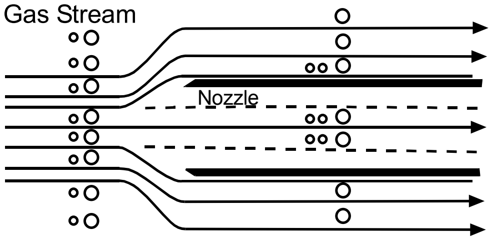


Figure 7-5. Under Isokinetic Conditions

The probe nozzle also has requirements on its design and construction in order to provide the correct sampling results. The nozzles must be of the buttonhook or elbow design and have a sharp tapered edge. The angle of the taper must be ≤ 30° with the taper on the outside to preserve a constant internal diameter. This design reduces the disruption of the gas flow streamline. Nozzles can be constructed of seamless stainless steel (316) tubing, glass or other approved materials. Each nozzle must have a calibrated and maintained inside diameter. Nozzles that are not constructed with this design (i.e., sharp tapered edge) or are out of calibration due to dents should not be used.

The isokinetic rate equation relates the measured value of the pressure drop, Δp, from the pitot tube to the pressure drop, ΔH, across the orifice meter (see Figure 7-6), which is needed to sample isokinetically. The simple form of the isokinetic rate equation is $\Delta H = K\Delta p$, where K is an assemblage of constants and parameters that are obtained from equipment calibrations and collected source parameters. The working form of the isokinetic rate equation is:

$$\Delta H = \{846.72\ D_n^4\ \Delta H_{@}\ C_p^2\ (1 - B_{ws})^2\ \frac{M_d}{M_S}\frac{T_m}{T_s}\frac{P_S}{P_m}\}\ \Delta P$$

Where:

D_n = nozzle diameter
$H_{@}$ = Orifice constant
C_p = pitot tube constant
B_{ws} = stack moisture
M_d,M_s = molecular weights of stack gases on dry and actual basis
P_S,P_m = absolute pressure of stack gas and meter, respectively

The most effective means of capturing condensable gaseous pollutants during stationary source sampling is through condensation.

4. **Separation of Gas Constituents.** A known quantity of the stack gas is then drawn from the stack or duct through a *sampling train*, or a leak-proof series of equipment components configured to capture pollutants (see Figure 7-6). Capturing water vapor and gaseous pollutants is best achieved by condensation—or bubbling the sample gas through chilled *impingers* (sealed glass vessels), some which may contain liquid *reagents* to absorb gases.

Solids are captured on filter paper, which is heated and connected to the probe with inter-connecting glassware. The first component of the sampling train is a heated probe, or a hollow glass tube that is inserted into the stack or duct. The last component—a pump—draws gases through the other pieces of equipment (the probe, filters and impingers). The volume of sampled gas is measured by a gas meter and is finally exhausted into the atmosphere through the orifice, which is used for sample train flow adjustments at the by-pass valve.

5. **Sample Recovery and Analysis.** Filters are pre-weighed and reagent volumes pre-measured prior to use. After each run, the content of each sampling train component is carefully recovered to a sealed vessel, then weighed, measured, or otherwise evaluated under laboratory conditions.

6. **Data Recording.** Throughout each run, appropriate measurement data are recorded. On a point-by-point basis, the sampling time, sample train vacuum, differential pressures across the gas temperature, orifice meters, and dry gas meter readings are recorded. Averages of these values, along with the total sample gas volume, are then used to calculate the test results.

7. **Calculation of Results.** The *concentration* of a pollutant in the sampled gas is calculated as the proportion of captured pollutant's mass to the volume of gas sampled. These results are corrected to a standard temperature and pressure and expressed on a dry basis. This *standardized measure* allows the results of a test performed under specific conditions to be comparable to a regulatory standard or other test results.

The term isokinetic sampling is defined as equal or uniform sampling of gas in motion. This is accomplished when the fluid streamlines of the stack gases are not disturbed. A 100% isokinetic source sample is taken when the gas velocity into the sample nozzle (v_n) is equal to the velocity of the approaching gas stream velocity (v_s). The isokinetic variation (I) is calculated to determine if results are within acceptable limits of $90\% \geq I \leq 110\%$. The isokinetic variation equation is:

$$\% \text{ Isokinetic variation} = \frac{v_n}{v_S} \times 100$$

8. **Expression of Results.** For wider applicability among sources and states, the pollutant concentration can be used to calculate other expressions of the test result. For instance, a gas flow rate may be used with the concentration to calculate an *emission rate* for the pollutant or the amount emitted per unit of time.

The similarity of the sampling methods and equipment allow a measure of interchangeability and interrelation, so that multiple methods may be conducted simultaneously with a single sampling train simply by adding impingers, filters, or other appropriate capture devices. For example, Method 5 (for particulate emissions) and Method 8 (for sulfuric acid mist and sulfur dioxide) are easily combined by adding additional impingers and an in-stack filter to the probe on the Method 5 sampling train. When gas velocity measurements are required for calculating test results, Method 2 is incorporated with any other method simply by strapping the velocity probe to the sampling probe. Velocity measurements are read from a manometer connected to the velocity probe. However, Method 5 (for particulate emission) is typically combined with Method 2 (for gas velocity), Method 3 (for molecular weight), and Method 4 (for gas moisture content). These supportive measures—velocity, molecular weight, and moisture content—are required to calculate a particulate emission rate.

Manual source sampling was very labor intensive and time consuming, so instrument methods were first promulgated during the 1980s.

Instrument methods are a special case of source sampling that requires a gas analysis by the use of a continuously recording instrument. Effluent gas from a stack or duct is extracted and passed to one or more continuously analyzing instruments. The analytical results are either signaled to a strip chart recorder or to a data acquisition system. Strip charts are automatically drawn line graphs that must be interpreted by a technician as numerical values and reduced to averages over appropriate time periods. However, the method of data acquisition most often used is by computers that record and reduce the data, store it, and produce appropriate reports. Instrumental methods were first promulgated during the 1980s and continue to be developed as technology advances.

In addition, there is a dramatic need to provide “real-time” (immediate) measurements rather than waiting for days or weeks to obtain wet chemistry test results. Advancements in instrumental analyzers have permitted air pollution scientists to move toward replacing periodic measurements with continuous emission monitoring (CEM). Modern instrumental test methods and analyzers can quickly identify many metals and organic compounds at very low concentrations. Instruments such as these are the current focus of important research.

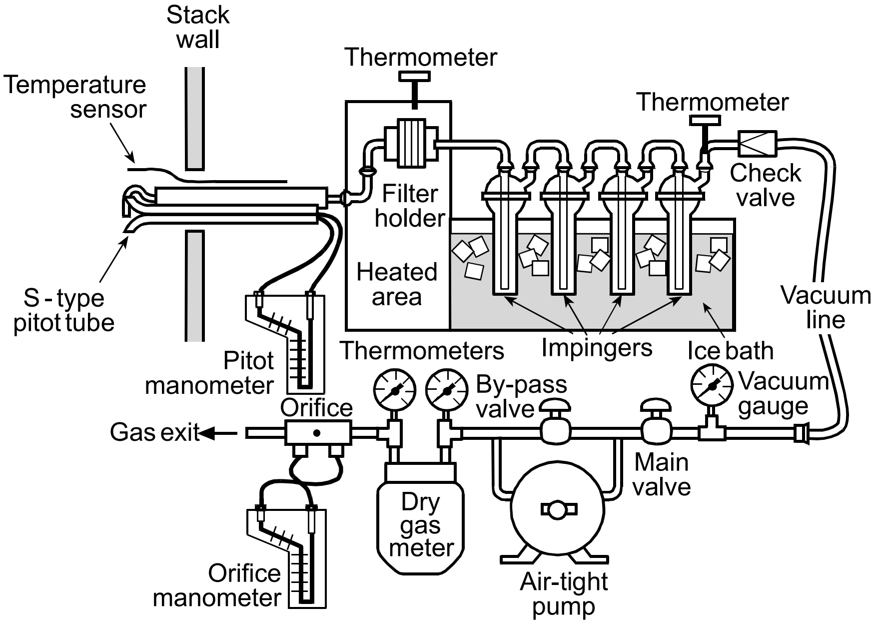


Figure 7-6. Sampling Train for Particulate Emissions

Continuous Emission Monitoring

Continuous Emission Monitoring (CEM) is achieved by continuously recording source emissions using instrument methods.

Because manual source sampling is a time-consuming and labor intensive process, attention has shifted to finding ways to use a more efficient, automatic approach. In addition, process and control equipment are tuned to peak performance for infrequent manual testing. For this reason, other measurement techniques are necessary.

By the early 1970s, advancements in German and American instrumentation offered new options for measuring gaseous pollutants. In fact, German optical systems have shown great promise for measuring *opacity*, a parameter that relates to particulate matter concentration of the stack gas (see Figure 7-7).

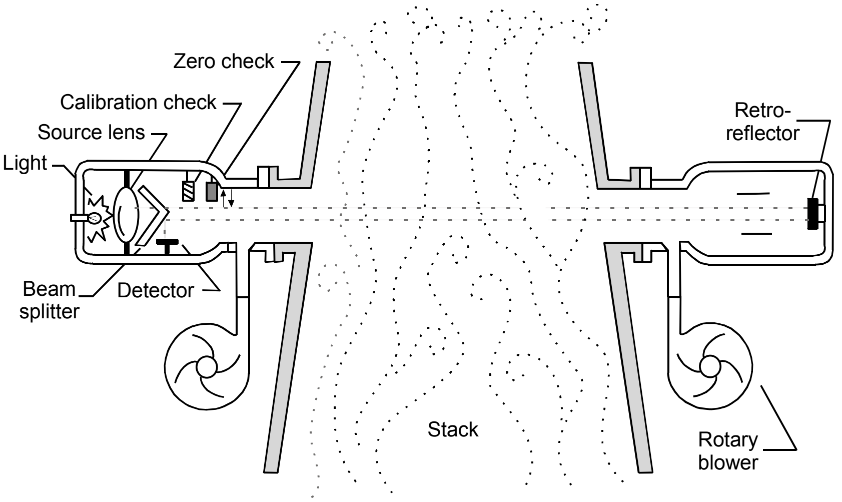


Figure 7-7. Double Pass Opacity Monitor

There are many different types of instruments and systems for monitoring emissions from stationary sources. However, generally these systems can be classified into two basic groups: extractive and *in-situ* systems (see Figure 7-8). Extractive gas/Continuous gas monitoring systems were first developed for use in source measurements. Extractive systems can be further categorized as either dilution or direct. Instability of dilution ratios can occur in dilution systems, which can cause reporting errors.

In-situ analyzers monitor particulate or gas streams without sample extractions.

In-situ analyzers directly measure effluent gases at actual source-level concentrations without diluting or modifying the original gas composition (i.e., removing particulate or interfering gases) as *extractive* systems had required. *In stack situ* CEMs are also able to tolerate environmental conditions at most locations and have fewer subsystems (i.e., probe heaters, gas conditioning systems, tubing and pumps) than their extractive predecessors. There are two types of *in-situ* analyzers: point and path. Point measurement is usually performed by the monitor's sensor over a path of only a few centimeters distance. Path CEM instruments perform this measurement across the entire duct or stack.

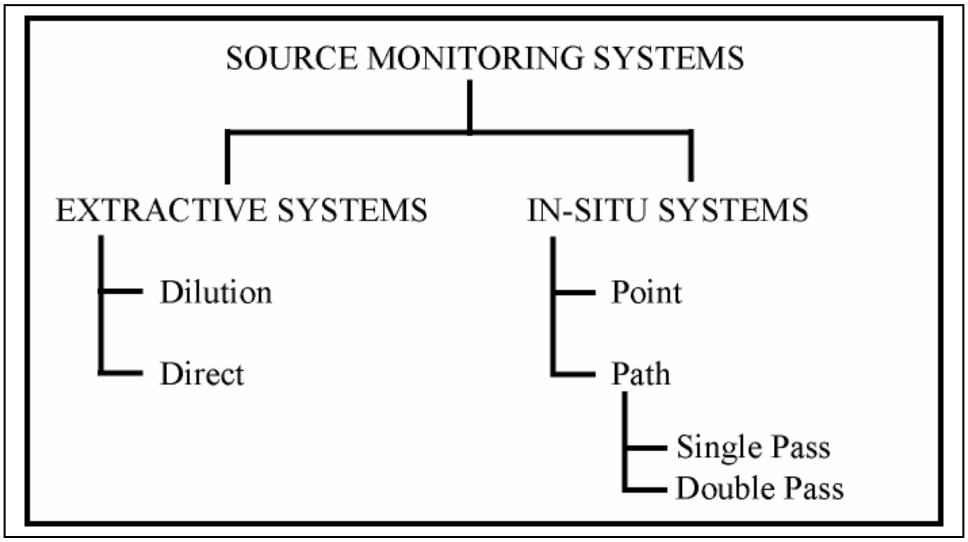


Figure 7-8. System Source Monitoring Classification Diagram (Jahnke, 1992)

CEMs have become an integral part of emission measurement technology, the regulatory environment, and air pollution control programs.

In 1975, the U.S. EPA established performance specifications for CEMs and required their installation in a limited number of sources, originally to monitor the effectiveness of air pollution control equipment. The acid rain control program, mandated in the 1990 Clean Air Act Amendments, required the use of CEM systems to determine the "allowances" or the number of tons per year of SO_2 emissions that may be traded between the electric power utilities. CEMs have also been applied toward providing valuable industrial process information.

During the past two decades, many problems have been overcome to refine the performance of CEM systems, and a wide range of chemical and physical analysis technologies have been developed to meet diverse measurement needs. Along with extended confidence in the technology and the resulting data, the use of CEMs has been extended in order to determine source compliance with emission standards. Today, CEMs are an indispensable part of emission measurement technology, the regulatory environment, and air pollution control programs.

Compliance Assurance Monitoring

EPA establishes emissions standards to protect public health and the environment. It is therefore important that affected facilities comply with these standards. On October 8, 1997, the USEPA published the final rules regarding Compliance Assurance Monitoring (CAM), as required under Title VII of the Clean Air Act Amendments of 1990. The CAM rule requires owners and operators to monitor the operation and maintenance of their control equipment so that they can evaluate the performance of their control devices and report whether or not their facilities meet established emission standards. If monitoring is conducted properly, facility owners will be able to assure state and local agencies, EPA, and the public that they comply with established emissions standards [hence the title Compliance Assurance Monitoring (CAM)]. Earlier stages this action was known as the "enhanced monitoring" rule.

Background

•The Clean Air Act includes provisions (Title V) that describe the requirements of permit programs, permit applications, as well as permit requirements and conditions. These provisions also address other aspects of the permits program such as compliance, enforcement, submission of applications, and approval of permits.

•EPA requires facilities that emit pollution into the air to obtain a permit to operate. This permit (known as an "operating permit") contains information about how the facility will comply with established emissions standards and guidelines. Operating permits provide facility owners, State inspectors, and the public with specific information about the air pollution regulations that apply to each facility. The operating permits program will improve compliance with existing regulatory requirements and ensure that desired emission reductions actually occur and are maintained.

•The Clean Air Act Amendments (Title VII) of 1990 also authorize EPA to develop regulations requiring facilities to monitor the performance of their emission control equipment.

In September 1993, EPA proposed an “enhanced monitoring” rule that established general monitoring criteria that facilities should follow to demonstrate continuous compliance. Many state and local agencies, industry representatives and other stakeholders strongly criticized the proposed rule. They believed the proposed rule was overly prescriptive and would have imposed excessive burden on industry to install and operate continuous emission monitoring equipment and on State and local agencies in implementing their operating permit programs.

•Since April 1995, EPA held numerous meetings with major stakeholders to develop a new, more flexible approach to enhanced monitoring. Through this stakeholder process, EPA redrafted the enhanced monitoring rule and in September 1995, released a new draft rule that changed the focus to compliance assurance. Based on comments received on the draft CAM rule EPA revised and issued a second draft for public comment on August 2, 1996. The final rules were published on October 8, 1997.

CAM Rule Main Components

•The CAM rule establishes criteria that define what monitoring of existing control devices that the source owner or operator should conduct to provide reasonable assurance of compliance with emission limits and standards. This monitoring will help source the owner or operator certify compliance under the Title V operating permits program.

•The CAM rule includes Title V compliance certification language that allows the source owner or operator to use compliance assurance monitoring data to establish their compliance status with permit terms or conditions. They can then use this information to certify that their facilities comply with air pollution control requirements, as required by the Clean Air Act.

•For situations where continuous compliance monitoring is already specified in an operating permit, the rule exempts the owner or operator from additional CAM rule-related monitoring requirements and directs the owner or operator to use the continuous compliance monitoring data to fulfill the CAM rule monitoring and certification requirements.

•For emission units with control equipment, the rule requires the owner or operator to develop and conduct monitoring. The monitoring will include an acceptable range with in which to operate the control device (known as an "indicator range"). Generally, facility owners will use results of performance tests in conjunction with equipment design or other information to determine the indicator ranges that (if the equipment is operated within those ranges) will provide a reasonable assurance of compliance with emission limitations.

- Operating control devices within acceptable ranges, as they were designed to operate, will minimize emissions and provide reasonable assurance that the facility is complying with permit terms and conditions.

- If the control equipment is found to be operating outside the indicator range for long periods of time, the CAM rule provides optional tools for the State or local (or Federal if necessary) permitting authority to require more intensive evaluation and improvement of control practices.

- If control equipment is found to be operating outside acceptable ranges, owners and operators will be required to take prompt corrective actions to make necessary adjustments to the control equipment, as well as notify State and local authorities that potential compliance problems may exist.

NAME ____________________________________ DATE _______________SCORE________

CHAPTER 7 MEASUREMENT OF POLLUTANT EMISSIONS

Multiple Choice

Directions: Read each question and choose the best answer. Write the letter of your answer in the space provided.

1. Federal Reference Methods 1-8 were originally promulgated in _______.

a. 1967
b. 1971
c. 1979
d. 1981
e. 1990

1. ________

2. The most effective means of capturing condensable gaseous pollutants during stationary source sampling is through _______.

a. electrostatic precipitation
b. filtration
c. condensation
d. centrifugal force
e. thermal precipitation

2. ________

3. In order to obtain a representative collection an isokinetic sample must be drawn into the sampling device at a _______.

a. velocity greater than the gas stream
b. velocity less than the gas stream
c. volume greater than the gas stream
d. velocity equal to the gas stream

3. ________

4. Sampling velocities that are greater than the isokinetic rate result in the collection of _______.

a. a smaller number of small particles than those found in the gas stream
b. smaller volumes than those found in the gas stream
c. a larger number of small particles than those found in the sampled gas stream
d. the same proportional volumes as those found in the gas stream
e. the number of particles equal to those found in the gas stream

4. ________

5. Sampling velocities that are less than the isokinetic rate results in the collection of _______.

a. a smaller number of small particles than those found in the gas stream
b. smaller volumes than those found in the gas stream
c. a larger number of large particles than those found in the gas stream
d. larger volumes than those found in the gas stream
e. the number of particles equal to those found in the gas stream

5. ________

6. Misalignment of the sample probe results in a measurement error that could cause ________.

a. smaller particle to not be included in the collected sample
b. smaller volumes of gas
c. some larger particles to not be included in the collected sample
d. larger volumes of gas to be collected
e. equal volumes of gas

6. ________

7. The ________ nozzle tapered from the outside inward results in the least disruption of the gas flow streamline.

a. square-edged
b. blunt-edged
c. curved-edged
d. sharp-edged
e. fork-edged

7. ________

8. Nozzles whose design not include sharp and tapered edges, or are dented ________.

a. are allowed for use in a Method 5 sampling train
b. collect all particles better than other nozzles
c. collect small particles better than other nozzles
d. collect smaller volumes of sample gas than other nozzles
e. should not be used for particle sampling

8. ________

9. Industry does **not** use the results of stationary source testing to ________.

a. evaluate process economics
b. control operational costs
c. evaluate existing control device efficiency
d. design new emission control equipment
e. impose fines and penalties for non-compliance

9. ________

10. Compliance Assurance Monitoring (CAM) reporting and record keeping are found in _______ of the 1990 Clean Air Act.

a. Title VII
b. Title V
c. Title VIII
d. Title VI
e. Title III

10. ______

Matching

Directions: Match the Federal Reference Method with the item description.

Federal Reference Methods

_______ **11.** Reference Method 1

_______ **12.** Reference Method 2

_______ **13.** Reference Method 3

_______ **14.** Reference Method 4

_______ **15.** Reference Method 5

_______ **16.** Reference Method 6

_______ **17.** Reference Method 7

_______ **18.** Reference Method 8

a. Gas Flow Rate

b. Nitrogen Oxides

c. Sampling Point Locations

d. Particulate Matter

e. Gas Molecular Weight

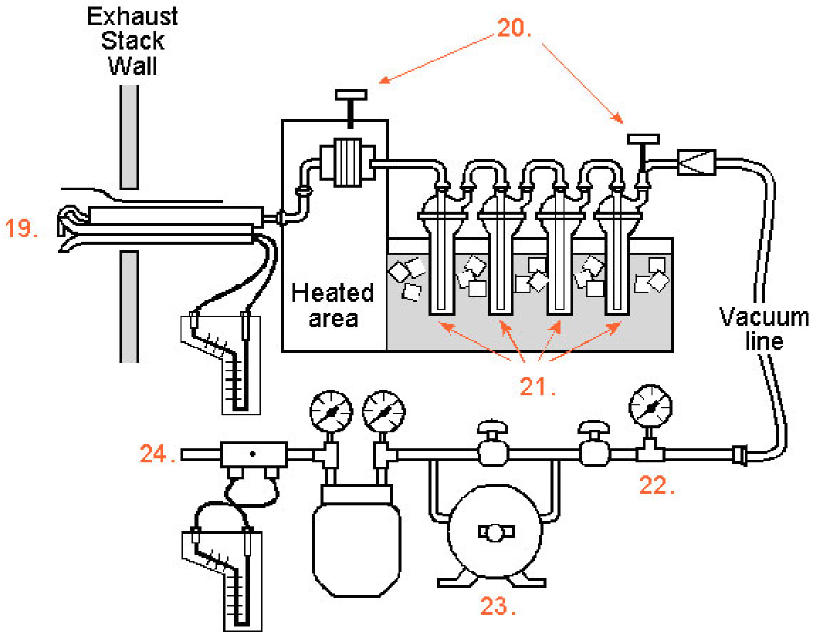
f. Sulfur Dioxide

g. Sulfuric Acid Mist and Sulfur Dioxide

h. Gas Moisture Content

Particulate Emission Sampling Train

Directions: Use the diagram below to identify specific equipment components.



19. ________________________________

20. ________________________________

21. ________________________________

22. ________________________________

23. ________________________________

24. ________________________________

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	B	7-4
2.	C	7-8
3.	D	7-7
4.	C	7-7
5.	C	7-8
6.	C	7-8
7.	D	7-8
8.	E	7-8
9.	E	7-3
10.	A	7-14
11.	C	7-5
12.	A	
13.	E	
14.	H	
15.	D	
16.	F	
17.	B	
18.	G	
19.	S-type pilot tube and Probe (gas entrance	7-9
20.	Thermometers or thermocouplers	
21.	Impingers	
22.	Vacuum gauge	
23.	Air-tight pump	
24.	Orifice (gas exit)	

CHAPTER 8

Emissions Inventory

Lesson Goal

Demonstrate an understanding of the purpose of the emissions inventory and its principal uses, its place in control strategy development, and general methods used to prepare an emissions inventory, emissions factors the various types of emissions inventories used in control strategy development by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Define the terms *emissions inventory* and *emissions factor*.
2. List and explain the elements of an emissions inventory.
3. Explain the uses of emissions.
4. Name the types of sources and classes of pollutants inventoried.
5. List examples of point, area, and line sources.
6. List and discuss five uses of the emissions inventory.
7. Explain the advantages of gross estimation inventory, rapid survey inventory, and comprehensive emissions inventory.
8. Identify the major types of emissions inventories, how they are developed, and when they are used.
9. Explain the role of emissions inventories in the development of control strategies.
10. Calculate emissions factors and describe the various types of emissions inventories used in control strategy development.

Recommended Reading: Godish, Thad, “Air Quality and Emissions Assessment,” *Air Quality*, 3rd Edition, New York: Lewis, 1997, pp. 215-236.

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U.S. EPA, National Commission on Air Quality (NCAQ), *Study of the Quality of Emission Inventories: Assessment of Emission Inventory Adequacy for Regulatory Programs*, Report to NCAQ (No. 22) by Arthur D. Little, Inc., Volume II, Washington, DC: NCAQ, 1981.

Emissions Inventory

Evaluating the cause of high concentrations of ambient air pollution is one of the most complex tasks in air pollution control. This task is made even more difficult by factors that influence pollutant behavior, such as topography, meteorology, and the diversity of source emissions. A starting point for pollution control is quantifying the emissions being released into the atmosphere. Therefore, an emissions inventory is essential to provide a current, accurate, and comprehensive listing of air pollution emissions within a specific area over a specified period of time. The amounts and types of emissions can change yearly depending on changes in the nation’s economy, industrial activity, technology improvements, traffic, and many other factors. Air pollution regulations and emissions controls, without question, have an important effect.

An emissions inventory is a detailed listing of pollutants emitted from specific sources in a defined area.

Careful and thorough planning of the inventory procedures will facilitate the process and prevent costly revisions. Various planning activities in preparing an emission inventory are shown in Figure 8-1. The first step of the inventory planning process is to define the scope of the proposed inventory. The pollutants, emission sources, source categories, and geographical boundaries all need to be identified before data collection begins. For most inventories, the geographic area covered is typically defined by political boundaries (county lines, city limits, and state borders). The inventory purpose determines the exact geographic area covered. Inventories developed for modeling purposes are based on the “modeling region.”

The modeling region is defined in terms of the grid boundary that outlines the region and accounts for the size of the individual grid cells, which will be used to subdivide the region. The next step is to specify the pollutants to be inventoried. This should be performed before the relevant source categories can be identified and prioritized. Pollutants can be selected based on their interest as ozone precursors, toxicity, or global warming (greenhouse gases). An effective inventory should also provide detailed pollution compliance information that can be used by the agency to identify the present and projected effect a pollutant may have on the ambient air quality of a region.

Ultimately, however, each state must develop a comprehensive set of emissions inventories in order to define the relationship between pollutant sources and their surrounding communities; develop pollution control strategies; or provide summary information about pollutants, sources, and emissions within their borders.

Emissions Inventory Activities include:

- *Planning*
- *Identification of Inventory Objectives*
- *Define Point/Area Categories*
- *Needs Analysis*
- *Data Collection*
- *Calculate Emissions*
- *Report Emissions*
- *QA / QC*

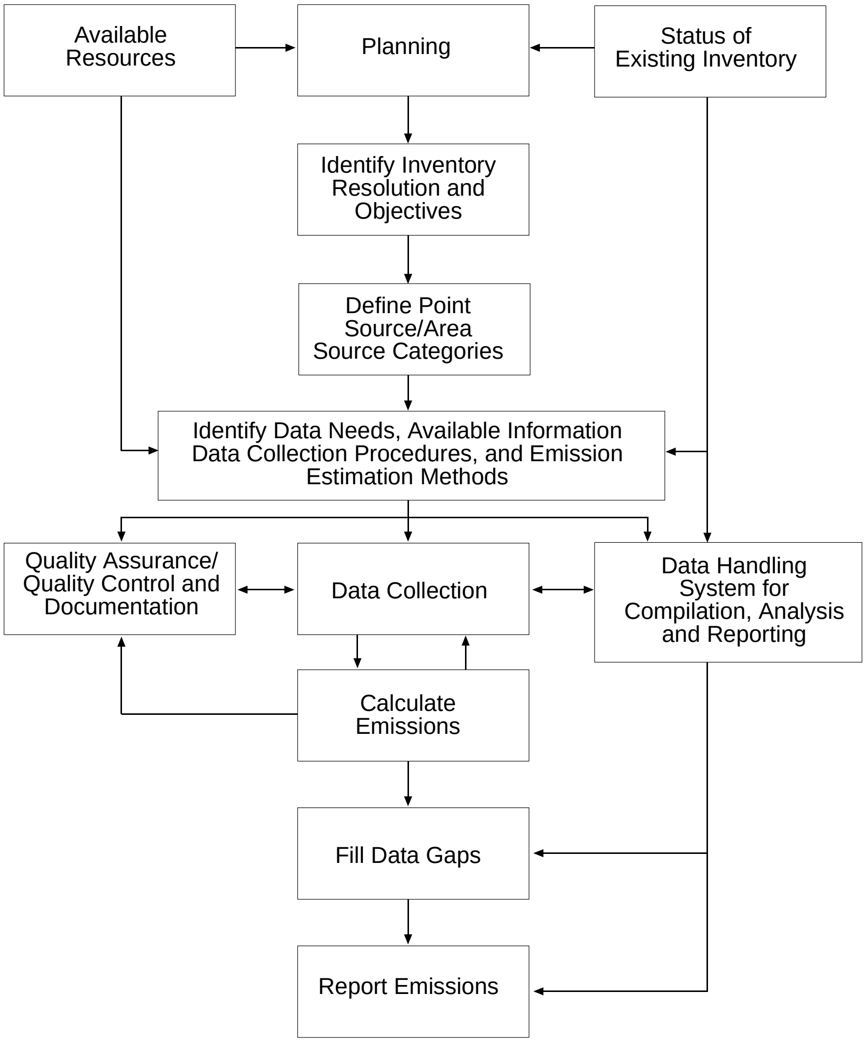


Figure 8-1. Activities for Preparing an Inventory

As part of the emissions inventory, detailed information about the types of sources that need to be included for a comprehensive listing should be addressed. The major types of sources are point, area, mobile, and biogenic.

Point sources are large, stationary sources of emissions that release pollutants in quantities above an emission threshold. For criteria pollutants, the emission thresholds are shown below in Table 8-1. Point source thresholds can also vary in nonattainment areas depending on classification.

Table 8-1. Emission Thresholds for Criteria Pollutants

Pollutant	**Emission Threshold for Point Sources[a] (tons per year)**
Carbon monoxide	1,000
Nitrogen oxides	100
Sulfur oxides	100
Particulate matter ≤10 μm	100
Particulate matter ≤2.5 μm	100[b]
Lead or lead compounds	5
Volatile organic compounds[c]	100

[a] Emission threshold as stated in 40 CFR 51; Subpart Q 51.322
[b] Emission threshold as stated in 40 CFR 51 Subpart 51.025
[c] VOC's are not criteria pollutants, but are precursors of the criteria pollutant ozone

In addition to the point source criteria pollutants, other compounds such as toxic or hazardous air pollutants or greenhouse gases may have a requirement to be inventoried. Area sources are facilities or activities whose individual emissions do not qualify them as point sources. Area sources represent numerous facilities or activities that individually release small amounts of a given pollutant, but collectively release significant amounts of a pollutant. For example, dry cleaners, vehicle refinishing, gasoline dispensing facilities, and residential heating will not typically qualify as a point sources, but collectively emit significant amounts of various emissions. Although they may not emit significant quantities individually, they must still be included in an emissions inventory. Mobile sources can be divided into on-road vehicles, which include automobiles, light

Major sources of pollution must be identified for a comprehensive Emissions Inventory. Major sources of pollution are point, area, mobile and biogenic sources.

trucks, heavy-duty trucks, buses, motorcycles and non-road vehicles, such as airplanes, trains, combustion engines on farm and construction equipment, marine engines, and lawn mowers.

Biogenic or natural sources include trees, vegetation, and other microbial activity that can make a significant contribution to total volatile organic compound (VOC) and nitrogen oxides (NOx) emissions. In the past, the impact of biogenic VOCs was not considered when ozone control strategies to limit emissions of either NOx or VOC were developed. However, the importance of biogenic VOC emissions in an ozone inventory became apparent in some regions when the biogenic VOC emission estimates were compared to anthropogenic VOC emission estimates.

Emissions estimation consists of two main approaches: the top-down approach and the bottom-up approach.

Estimation of Emissions. There are two main approaches in estimating emissions: the top-down approach and the bottom-up approach. A top-down approach estimates emissions based on national or regional estimates. A measure of activity data is used to scale the national estimates to the area of study. Typically, sales data, or per employee, or per capita emission factors are used. An advantage of the top-down approach is that it requires minimum resources by grouping like emission sources together and making use of readily available activity and emission data. One potential problem with this approach is that an emission estimate will lose some accuracy due to the uncertainty associated with the estimate and the representativeness of the estimate once it has been extrapolated to the local level. A bottom-up approach estimates emissions for individual sources and sums all sources to obtain state or county level estimates. This method requires more resources to collect site-specific information on emission resources, activity levels, and emission factors. However, the results are more accurate than a top-down approach because data are collected directly from individual sources.

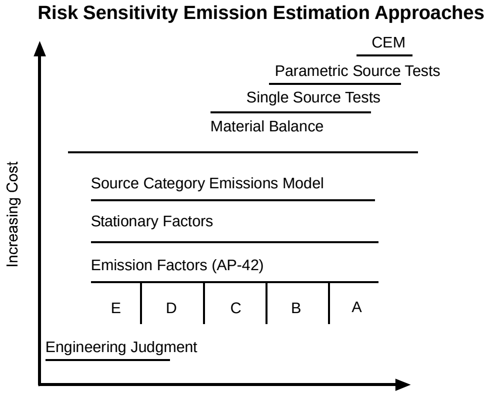


Figure 8-2. Approach to Emission Estimation

Figure 8-2 depicts various approaches to emission estimation, in a hierarchy of requirements and levels of sophistication that one should consider, when analyzing the tradeoffs between cost of the estimates and the quality of the resulting estimates. Where risks of either adverse environmental effects or adverse regulatory outcomes are high, more sophisticated and more costly emission determination methods may be necessary. Where the risks of using a poor estimate are low, and the costs of more extensive methods are unattractive, then less expensive estimation methods such as emission factors and emission models may be both satisfactory and appropriate. In cases where no emission factors are available but adverse risk is low, it may even be acceptable to apply factors from similar source categories using engineering judgment. Selecting the method to be used to estimate source-specific emissions may warrant a case-by-case analysis considering the costs and risks in the specific situation. All sources and regulatory agencies should be aware of these risks and costs and should assess them accordingly.

There are several methods for estimating emissions from specific source types some of which are shown in Figure 8-2. The most commonly used methods include the following:

a. *Continuous emission monitors* (CEMs). CEMs continuously measure (with very short averaging time) and record actual emissions during the time of monitor operation. CEMs data can also be used to estimate emissions for different operating and longer averaging times.

b. *Source testing,* Emission rates are derived from short-term emission measurements taken at a stack or vent. Emission data can then be extrapolated to estimate long-term emissions from the same or similar sources.

c. *Material balance.* Emissions are determined based on the amount of material that enters a process, the amount that leaves the process, and the amount shipped as part of the product itself.

d. *Emission factors.* An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. The activity chosen should be able to be easily measured, such as an amount of material processed, or an amount of fuel used. Given an emission factor and a known activity level, a simple multiplication yields an estimate of the emissions. Emission factors are developed from separate

Methods of estimating source emissions include:

- *Continuous Emission Monitors*
- *Source Testing*
- *Material Balance*
- *Emission Factors*
- *Fuel Analysis*
- *Emission Estimation Models*
- *Surveys and Questionnaires*
- *Engineering Judgment*

> facilities within an industry category, so they represent typical values for an industry, but do not necessarily represent a specific source burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average). Published emission factors are available in numerous sources. The US EPA's AP-42 series is one of these publications and is available electronically at: http://www.epa.gov/ttn/chief/.

Emission factor ratings in AP-42 provide indications of the robustness, or appropriateness, of emission factors for estimating average emissions for a source activity. Usually, data are insufficient to indicate the influence of various process parameters such as temperature and reactant concentrations. For a few cases, however, such as in estimating emissions from petroleum storage tanks, this document contains empirical formulae (or emission models) that relate emissions to variables such as tank diameter, liquid temperature, and wind velocity. Emission factor formulae that account for the influence of such variables tend to yield more realistic estimates than would factors that do not consider those parameters.

Emission factors in AP-42 are neither EPA-recommended emission limits (i.e., best available control technology or BACT, or lowest achievable emission rate or LAER) nor standards (i.e., National Emission Standard for Hazardous Air Pollutants or NESHAP, or New Source Performance Standards or NSPS). EPA does not recommend use of these factors as source-specific permit limits and/or as emission regulation compliance determinations. Because emission factors essentially represent an average of a range of emission rates, approximately half of the subject sources will have emission rates greater than the emission factor and the other half will have emission rates less than the factor. As such, a permit limit using an AP-42 emission factor would result in half of the sources being in noncompliance.

An example of emission factors from AP-42 for gasoline service stations are shown in Table 8-2. The general equation for emission estimation is:

$$E = A \times EF \times (1 - ER/100)$$

Where:

E = emissions
A = activity rate
EF = emission factor
ER = overall emission reduction efficiency

ER is further defined as the product of the control device destruction or removal efficiency and the capture efficiency of the control system. When estimating emissions for a long time period (i.e., one year), both the device and the capture efficiency terms should account for upset periods as well as routine operations.

Table 8-2. Evaporative Emissions From Gasoline Service Station Operations[a]

Emission Source	*Emission Rate*	
	Mg/L Throughput	lb/10^3 gal Throughput
Filling underground tank (Stage I)	880	7.3
Submerged filling	1,380	11.5
Splash filling	40	0.3
Balanced submerged filling	120	1.0
Underground tank breathing and emptying[b]		
Vehicle refueling operations (Stage II)	1,320	11.0
Displace mentlosses (uncontrolled)[c]	132	1.1
Displacement losses (controlled)	80	0.7
Spillage		

[a] Factors are for VOC as well as total organic emissions, because of the methane and ethane content of gasoline evaporative emissions is negligible.
[b] Includes any vapor loss between underground tank and gas pump.
[c] Based on Equation 6, using average conditions.

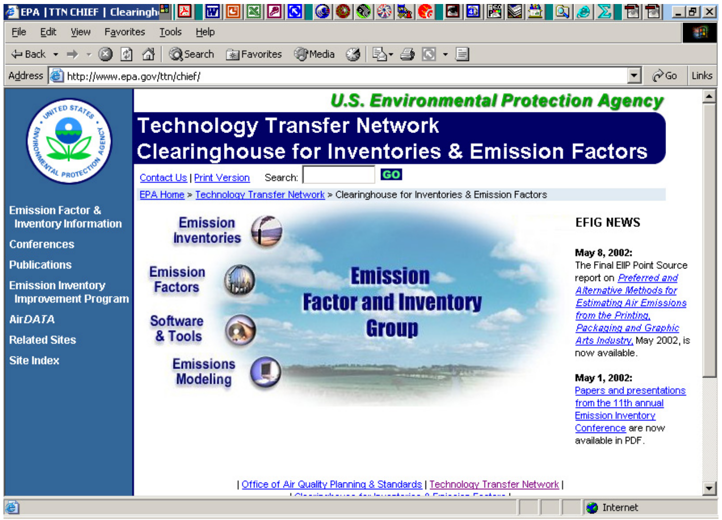
e. *Fuel analysis.* Emissions are determined based on the application of conservation laws. The presence of certain elements in fuels may be used to predict their presence in emission streams. For example, SO_2 emissions from oil combustion can be calculated based on the concentration of sulfur in the oil. This approach assumes complete conversion of sulfur to SO_2. Therefore, for every pound of sulfur burned (molecular weight = 32g), two pounds of SO_2 are emitted (molecular weight = 64g).

f. *Emission estimation models*. Emission estimation models are empirically developed process equations used to estimate emissions from certain sources. An example emission estimation model is the TANKS software for estimating volatile organic compounds emissions from fixed- and floating-roof storage tanks.

g. *Surveys and questionnaires.* Surveys and questionnaires are commonly used to obtain facility-specific data on emissions and their sources.

h. *Engineering judgment.* An engineering judgment is made when the specific emission estimation techniques such as stack testing, material balance, or emission factor are not possible. This estimation is usually made by an engineer familiar with the specific process, and is based on whatever knowledge may be available.

Chief Web Site. The U.S. EPA Office of Air Quality Planning and Standards (OAQPS) Technology Transfer Network has established the CHIEF (Clearing House for Inventory and Emission Factors) web site (http://www.epa.gov/ttn/chief) to aid in the development of inventories and for the estimation of air emissions and is shown in Figure 8-3.



http://www.epa.gov/ttn/chief/

U.S. Environmental Protection Agency

Technology Transfer Network
Clearinghouse for Inventories & Emission Factors

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Emission Inventories
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Emission Factor and Inventory Group

EFIG NEWS

May 8, 2002:
The Final EIIP Point Source report on *Preferred and Alternative Methods for Estimating Air Emissions from the Printing, Packaging and Graphic Arts Industry*, May 2002, is now available.

May 1, 2002:
Papers and presentations from the 11th annual Emission Inventory Conference are now available in PDF.

| Office of Air Quality Planning & Standards | Technology Transfer Network |

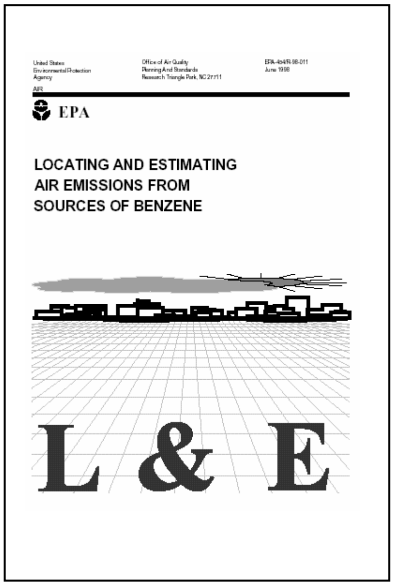
Figure 8-3. CHIEF Web Site

U.S. EPA CHIEF Web site may be found at http://www.epa.gov/ttn/chief/.

The CHIEF web site is the most comprehensive repository of documents and software products developed by the Emission Factor and Inventory Group. CHIEF primarily focuses on emission information for criteria and toxic pollutants from stationary sources, although some information is available for mobile sources. Also on the web site are links to other emissions inventory Web sites like the EIIP (Emission Inventory Improvement Program).

Locating & Estimating (L&E) Documents

The U.S. Environmental Protection Agency (EPA), State, and local air pollution control agencies are becoming increasingly aware of the presence of substances in the ambient air that may be toxic at certain concentrations. This awareness, in turn, has led to attempts to identify source/receptor relationships for these substances and to develop control programs to regulate emissions.



United States Environmental Protection Agency
AIR

Office of Air Quality Planning And Standards Research Triangle Park, NC 27711

EPA-454/R-98-011
June 1998

EPA

LOCATING AND ESTIMATING
AIR EMISSIONS FROM
SOURCES OF BENZENE

L & E

The report series, titled Locating and Estimating Air Toxic Emissions from Sources of (source category or substance) characterizes the source categories for which emissions of a toxic substance have been identified. These volumes include general descriptions of the emitting processes, identifying potential release points and emission factors. As standard procedure, L&E documents are sent to government, industry, and environmental groups wherever EPA is aware of expertise. These groups are given the opportunity to review a document, comment, and provide additional data where applicable.

Purpose of Emissions Inventories

Purposes of an Emissions Inventory:

- *Pollutant Identification*
- *Effect Studies*
- *Emission Reactivity*
- *Compliance*
- *Policy Development*
- *Ambient Air Monitoring*
- *Agency Requirements*

The reasons for developing an emissions inventory are often regulatory, although not exclusively so. Emissions regulations or statutes specifically require air emission inventories to determine the amount of pollutants released to the atmosphere. For example, the Clean Air Act (CAA) as amended in 1990 sets forth requirements for specific inventories such as State Implementation Plans (SIPs) base year inventories. In addition, the development of regulations often necessitates a nationwide inventory of emissions from a particular industry or type of emission source. On a smaller scale, inventories from a facility are used as the basis for construction and operating permits, determining compliance with existing permit conditions or emission regulations, conducting environmental impact assessments for proposed new sources, and for input to human health risk assessment studies under a variety of air quality management programs.

State and local agencies have used emissions inventories for years to quantify pollutant emissions within their locales. In planning an effective emissions inventory, it is important to understand the various purposes and objectives for which it was intended. State and local agencies have used emissions inventories for years to quantify pollutant emissions within their locales. In planning an effective emissions inventory, it is important to understand the various purposes and objectives for which it was intended. Agencies also need to develop emission inventory projections in order to account for as many variables that could affect future year emissions. Emission projections refer to extrapolating baseline emission estimates to predict future emissions based on expected future activity levels and emissions controls. Projected emissions estimates are often used for planning, evaluation of potential control measures, analysis of new source impacts, modeling of future air quality, and assessment of the effectiveness of air pollution control strategies for State Implementation Plans (SIPs). A baseline emissions inventory is important because it represents a snapshot of emissions for a given baseline year. However, because sources and their associated air emissions are not static over time, baseline emissions may not accurately represent emissions for a future year. Emission projections are an attempt to account for the effects of future growth and emissions controls.

Projections are usually not considered to be a modeling inventory development step. These steps are typically considered to be limited to temporal allocation, spatial allocation, and speciation. In fact, modeling inventory emissions that have been temporally allocated, gridded, and speciated are usually not projected into the future. Instead the annual baseline emissions data are projected. These projected emissions can then be temporally allocated, spatially allocated, and speciated to create modeling inventories of the projected emissions.

Historical Records. One of the primary reasons a control agency may choose to conduct an emissions inventory is to determine the types of pollutants and in what quantities they exist. Before a control strategy can be effectively developed, it is essential to first quantify emissions of pollutants generated within a specific geographic area and understand past emissions patterns. Generally, even the most basic inventory will contain a comprehensive catalog of source emissions.

Temporal and Spatial Distribution. A second use of the inventory is to establish a temporal and spatial distribution of pollutants in a region. In many cases, simply knowing the types and total amount of source emissions within a large geographic region may not be enough. The effect of hazardous pollutants may be compounded or (conversely) minimized by when and where the emission occurs. The effects of a pollutant may increase with exposure to the sun or moisture, or perhaps the atmospheric conditions may not adequately disperse the pollutant from a concentrated area.

An emissions inventory can help reduce the effects of pollution on human health and the environment by serving as the basis for a pollution prevention program.

Emission Reactivity. An emissions inventory also allows agencies to consider how pollution behaves as it interacts with other pollutants or natural elements in the surrounding environment. Almost all organic compounds which are emitted into the atmosphere undergo a photochemical reaction. However, some compounds are more reactive than others and have a quicker or more localized impact on air quality. In addition, pollutants released into the atmosphere may have little or no effect of their own on human health or welfare. However, when combined with other regional emissions, they may become very toxic. Therefore, a careful analysis of each organic emission within a region is essential to an effective control strategy.

Compliance. An emissions inventory is necessary in order to determine the potential effect a pollutant may have on its surroundings. Air pollution professionals must not only be able to identify and manage excess pollutant levels, but also significantly reduce or eliminate any pollutant that poses a risk to human health or the environment. The area emissions inventory is one step in that direction. This type of inventory effectively accounts for all known types and amounts of pollutants and better reveals excess exposure during normal monitoring periods. An accurate accounting of all emissions is indispensable to an agency that is required to employ pollution control strategies to reduce or eliminate toxic substances within an area. An accurate emissions inventory is often the first information required to establish a pattern of compliance with National Ambient Air Quality Standards.

The data from an emissions inventory can be used to form public policy and regulate hazardous pollutants.

Regulatory Development. Another use of the emissions inventory is to guide the development of public policy. A thorough assessment of emissions provides valuable information about which sources of pollution should be subject to stricter control and what effect the new emission standard might have on air quality. The inventory also provides valuable information to public debate that assesses the economic and social impacts on the area. Finally, the inventory provides a useful means for determining whether to issue or reauthorize source permits within a region.

Ambient Air Monitoring. An important use of the emissions inventory is to assist in the selection of sites for effective ambient air quality monitoring stations. The emissions data collected by an agency is used with existing meteorological data and available ambient air measurements to identify suitable sites for additional air monitoring and sampling. Using emissions information to locate optimal sites for ambient air monitoring is one of the most effective ways to evaluate violations of the National Ambient Air Quality Standard (NAAQS) and monitor source performance and progress.

Miscellaneous Agency Requirements. A final use of the emissions inventory is to meet the general information requirements of an air pollution control agency. Examples of such needs might include the ability to monitor and report industrial growth in a region, maintain current emission data on existing sources, and provide permit information for new source applications as required by public law. In this regard, an emissions inventory design should remain as flexible as possible to provide any additional information that may be required.

These seven uses of the emissions inventory provide only a brief overview of the ways in which an inventory may be used. Where sufficient resources are available, a well-constructed inventory can be as detailed or sophisticated as time and resources permit. However, the ultimate purpose of the emissions inventory is to assist in the development of an effective, regional air pollution control strategy (Hammerle, 1976).

Elements of an Emissions Inventory

Once there is some consensus regarding the objectives or purpose of a regional inventory, the planning and design of the inventory may proceed. Overall, the emissions inventory affords the pollution control executive the ability to study the relationship between an emission and its effect on ambient air quality. While the final design may be more detailed and extensive than that required by legislation, effective inventories provide probative information about the future needs and requirements of a region. In order to

Emission Inventory Elements:

- *Geographical Area*
- *Spatial and Temporal Characteristics*
- *Source Specific Data*
- *Pre-existing Inventory Data*
- *Data Handling*

design an effective inventory, certain essential elements must be included.

Geographic Area. The first element of the emissions inventory is to clearly define the boundaries of an appropriate geographic area to be studied. Too large an area can inflate the scope and detail of an emissions inventory. For this reason, it is important to define an area that will not include more sources than can be adequately inventoried and monitored. The emissions inventory can only be as accurate as the agency's ability to identify and sample each point, area, or mobile source of pollution. For example, a petroleum refinery may contain many emission points ranging from process heaters to individual seals and pumps. As industrial profiles increase within a region, the requirement for more resources and personnel to manage the emissions inventory of the area increases as well. Agencies with limited resources could narrow the inventory by concentrating on those sources of greatest concern.

Spatial and Temporal Characteristics. The spatial and temporal characteristics of a source describe when and where emissions occur. *Spatial characteristics* are those characteristics that define the location of point sources using the Universal Transverse Mercator, or UTM, grid coordinates. Although these coordinates may be broadly expressed in latitude and longitude, the preferable method is to determine the eight- or ten-digit grid coordinate location for each source. The advantages of using UTM coordinates include the fact that emission points can be more precisely located (usually within 5 meters of their exact location), grids are continuous and unhindered by political subdivisions, and UTM coordinates are a uniform standard of measurement worldwide (see Figure 8-4).

Temporal characteristics of a source report the type and quantity of pollutants emitted over time, reports ranging from annual to hourly observations that document the temporal variations of a source. Emissions data are historically reported for a calendar year since most activity occurs on an annual basis. However, in some cases the agency may need to adjust annual emission rates to seasonal, daily, or hourly rates to accurately reflect the performance patterns of the site.

For example, some sources may only operate during certain hours of the day or certain seasons of the year. In addition, the activity levels of some mobile sources, surface coating, or pesticide operations are strongly dependent on the time of day and season of the year. In most cases, road re-surfacing projects are best completed during warmer months due to the hot tar materials used. These and other temporal and spatial variations of emissions must be considered by the pollution control agency.

Factory Stack
(Boiler)

	A	B	C
3	0	1.000	0
2	0	0	0
1	0	0	0

Factory Vent
(Coating Process)

	A	B	C
3	0	1.000	0
2	0	0	0
1	0	0	0

Highway Vehicles

	A	B	C
3	.200	.200	.200
2	.200	0	0
1	.200	0	0

Gasoline Stations

	A	B	C
3	.667	0	0
2	0	0	0
1	.333	0	0

Residential Consumer
Solvent Use

	A	B	C
3	0	0	0
2	.250	.250	0
1	.250	.250	0

Agricultural
Pesticide Use

	A	B	C
3	0	0	0
2	0	0	.500
1	0	0	.500

Figure 8-4. Spatial Allocation of Emissions to Grid Cells

Spatial and temporal characteristics of a source describe when and where emissions occur.

Spatial characteristics *are those characteristics that define the location of point sources using UTM grid coordinates.*

Temporal characteristics *of a source report the type and quantity of pollutants emitted over time.*

Smokestack location, height, diameter, and control device technology are examples of source specific data.

Source Specific Data. Once the geographic boundaries have been properly defined and the types of data that will be recorded for an area established, the agency must next consider what source-specific data will be required. This data may include the location of an exhaust stack, stack parameters, control devices in use, and other physical characteristics of the emission source. The accuracy of plant or facility data is essential to the production of an effective emissions inventory.

Pre-Existing Inventories. Another tool frequently overlooked is whether any pre-existing inventories may exist for the region or a portion of the area under consideration. Pre-existing inventories can be particularly useful to those agencies faced with limited or declining resources. Under such conditions, it may be possible simply to modify or extract relevant data from the existing emissions inventory. At the very least, an existing inventory may provide a good starting point from which a new assessment may be constructed. Although there are always many questions about how a previous inventory should be used, such decisions must ultimately be guided by how much information the agency currently has, what a new inventory might achieve, and the number of resources available to accomplish the task.

Data Handling. A final element of the emissions inventory is the method in which data will be handled and retrieved. Manual and computer-assisted data recovery are the two basic approaches to effective data handling. Determining which approach to use involves consideration of the availability of computer hardware and software, the volume and complexity of data to be processed, availability of trained personnel, and time. Computer data processing becomes significantly more cost effective as the database increases.

Emissions Inventory Process:

- *Identify Emissions Goals*
- *Gather Source Specific Data*
- *Review and Revise Data*

In addition, repetitive administrative tasks such as submitting routine status reports, emission summaries, and data storage and sorting are more efficiently accomplished by use of a computer. Using an automated data handling system permits an agency to spend more time gathering and validating inventory data and less time processing it. A computerized approach is far superior for large areas composed of diverse emission sources and a complex inventory. However, the decision to use computer-assisted designs is best made early in the planning process (USEPA, 1981).

Prior to compiling a comprehensive emissions inventory, it is necessary to define the purpose or objective for creating the assessment. The next step is to ensure the inclusion of essential elements into the planning process prior to gathering source data. As work progresses to clearly define an accurate inventory of source emissions for a region, each element should be repeatedly reviewed and revised to guarantee the accuracy of the emissions inventory. If this process is carefully observed, the resulting emissions inventory will be a useful tool in the development of an effective air pollution control strategy.

Quality Assurance and Quality Control Procedures for Emission

Inventory Preparation. A comprehensive QA program is essential to the preparation of a reliable, defensible emissions inventory. One shortcoming of many inventory development programs is that inadequate resources are devoted to QA/QC activities. A general rule of thumb used by many QA professionals is that 10 percent of the allocated resources should be used for QA activities. An effective QA program will include planning, numerous QC checks during inventory development, and QA audits at strategic points in the process. A QA program is composed of two distinct components:

- *Quality Control*. A system of routine technical activities implemented by the inventory development team to measure and control the quality of the inventory as it is being complied. QC procedures include technical reviews, accuracy checks, and the use of approved standardized procedures for emission calculations.

- *Quality Assurance.* A system of external review and audit procedures conducted by personnel not involved in the inventory process. QA is an independent, objective review by a third party to assess the effectiveness of the QC program and the quality, completeness, accuracy, precision and representativeness of the inventory.

As work progresses to clearly define an accurate inventory of source emissions for a region, each element should be repeatedly reviewed and revised to guarantee the accuracy of the emissions inventory. However, if this process is carefully observed, the resulting emissions inventory will be a useful tool in the development of an effective air pollution control strategy.

NAME ______________________________________ DATE _______________SCORE_________

CHAPTER 8 EMISSIONS INVENTORY

Multiple Choice

Directions: *Read each question and choose the best answer. Write the letter of your answer in the space provided.*

1. Calculate the amount of VOC emissions from the balanced submerged filling operation of a small service station, with a 2,000-gallon gasoline throughput. The evaporative emission factors for service stations are shown in Table 8-2 (p.8-9).

a. .6 lbs
b. 1.2 lbs
c. 1.8 lbs
d. 2.4 lbs
e. 3.2 lbs

1.________

2. Calculate the amount of VOC emissions for the controlled vehicle refueling displacement losses of a small service station with an 8,000-gallon gasoline throughput. The evaporative emission factors for service stations are shown in Table 8-2 (p.8-9).

a. .6 lbs
b. 7.2 lbs
c. 6.8 lbs
d. 8.8 lbs
e. 9.2 lbs

2. ________

3. The cornerstone of emission estimation and assessment activities is _______.

a. Locating and Estimating Series (L& E S) for hazardous air pollutants
b. AP-42
c. NAAQS
d. Clean Air Act (1963)
e. State Implementation Plans (SIPs)

3. ________

4. The purpose of a Historical Trend Emissions Inventory is to ________.

a. track emissions by source category over time
b. provide a detailed inventory of individual sources for a specific year
c. provide an episodic inventory with detailed spatial, temporal, and species resolution
d. estimate future emissions by source category
e. track actual vs. projected emissions reductions for a specific area over a specified period of time

4. ________

5. The purpose of a Projection Emissions Inventory is to ________.

a. track emissions by source category over time
b. provide a detailed inventory of individual sources for a specific year
c. provide an episodic inventory with detailed spatial, temporal, and species resolution
d. estimate future emissions by source category
e. track actual vs. projected emissions reductions for a specific area over a specified period of time

5. ________

6. The annual reporting requirements threshold amount for all criteria pollutants, except lead and carbon monoxide is ________.

a. 5 tons/year
b. 10 tons/year
c. 100 tons/year
d. 1000 tons/year
e. 25 tons/year

6. ________

7. The following are all essential elements of an emissions inventory, **except** ________.

a. geographic area criteria
b. spatial and temporal characteristics
c. source specific data
d. data handling techniques
e. enforcement strategies

7. ________

8. A listing of average emission rates that can be expected from individual source processes under specific operating parameters is a(n) ________.

a. Emission Inventory
b. Emission Factor
c. Emission Estimation
d. Emission Averaging
e. Modal Inventory

8. ________

9. A listing and description of air pollutant emitting sources is a(n) ________.

a. Emission Inventory
b. Emission Factor
c. Emission Estimation
d. Emission Averaging
e. Modal Inventory

9. ________

Matching

Directions: Match each of the following pollutant sources with the proper terminology.

Pollutant Source Identification

A. Point Source
B. Area Source
C. Mobile Source

_______ **10.** Commercial/Institutional Heating

_______ **11.** Power Plants

_______ **12.** Aircraft

_______ **13.** Industrial Processing Plants

_______ **14.** Channel Vessels

_______ **15.** On-Site Incineration

_______ **16.** Solid Waste Disposal Plants

_______ **17.** Open Burning

_______ **18.** Residential Heating

_______ **19.** Industrial Fuel Combustion

_______ **20.** Tractor Trailer Transport (Highway)

_______ **21.** Ferry Transports

_______ **22.** Evaporative Losses

_______ **23.** Municipal Incinerators

_______ **24.** Fugitive Emissions

_______ **25.** Barges

_______ **26.** Bus Transport

_______ **27.** Motor Vehicles

_______ **28.** Coast Guard Patrol Ships

_______ **29.** Port Vessels

_______ **30.** Rail Yard Locomotives

_______ **31.** Tug Boats

National Emission Estimates

Directions: *Review the national emissions estimates below and answer the questions in the spaces provided.*

Sources	**Carbon Monoxide**		**Particulate Matter (PM_{10})**		**Nitrogen Oxides**		**Sulfur Oxides**		**Totals**	
	1970	**1993**	**1970**	**1993**	**1970**	**1993**	**1970**	**1993**	**1970**	**1993**
Transportation	98.64	75.26	0.46	0.59	9.02	10.42	0.43	0.72	123.06	95.29
Stationary Sources Fuel Combustion	4.63	5.43	2.87	1.21	11.69	11.69	23.46	19.27	43.37	38.25
Industrial Processes	9.84	5.28	7.67	0.61	0.91	0.91	7.09	1.86	37.84	14.86
Solid Waste Disposal	7.06	1.73	0.99	0.25	0.08	0.08	0.01	0.04	10.12	4.37
Miscellaneous	7.91	9.51	0.84	1.03	0.30	0.30	0.10	0.01	10.25	11.74
Totals	**128.08**	**97.21**	**12.84**	**3.69**	**22.00**	**23.40**	**31.09**	**21.89**	**224.66**	**169.50**
Percent	**57.00**	**57.40**	**5.70**	**2.20**	**9.80**	**13.80**	**13.8**	**12.90**	**100.00**	**100.00**

(Source: USEPA, 1994. EPA/454/R-94-027. In: Godish, Thad. *Air Quality* (3rd edition). Lewis: New York, 1997, p. 29.)

32. Although the gross national emissions of criteria pollutants decreased _________ 10^6 short tons/year between 1970 and 1993, emissions increased for ______________________________.

33. Carbon monoxide emissions from transportation declined; however, emissions from ____ continued to increase.

34. The criteria pollutant that was the most significantly reduced was ________________________.

35. Pollution generated from solid waste disposal declined _______________ 10^6 short ton/year.

36. Rank the criteria pollutants by emission levels (10^6 short ton/year), based in given data and state the delta in the levels.

Table 8.2 Estimates of Criteria Pollutants, 1970 and 1993 (10^6 short ton/year)

	Source	1970	1993	Delta
1.				
2.				
3.				
4.				

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	A	8-9
2.	D	8-9
3.	B	8-7
4.	A	8-12
5.	D	8-12
6.	C	8-5
7.	E	8-12
8.	B	8-7
9.	A	8-3
10.	B	#10-31 are covered on 8-5
11.	A	
12.	B	
13.	A, E	
14.	C	
15.	B	
16.	B	
17.	B	
18.	B	
19.	A	
20.	C	
21.	C	
22.	B	
23.	A	
24.	B	
25.	C	
26.	C	
27.	B	
28.	B	
29.	B	
30.	B	
31.	B	
32.	55.16 and nitrogen oxides	
33.	Stationary sources of fuel combustion	

34. Carbon monoxide

35. 5.75

36. See completed table.

Table 8.2 **Estimates of Criteria Pollutants, 1970 and 1993 (10^6 short ton/year)**

	Source	1970	1993	Delta
1.	Carbon monoxide	128.08	97.21	- 30.87
2.	Nitrogen oxides	22.00	23.40	+ 1.40
3.	Sulfur oxides	31.09	21.89	- 9.20
4.	Particulate matter	12.84	3.69	- 9.15

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CHAPTER 9

Control of Stationary Sources (Particulate Matter)

Lesson Goal

Demonstrate an understanding of the basic principles, equipment, and methods used to control particulate emissions generated by stationary sources of air pollution by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Describe the basic principles, equipment, and methods used to control particulate emissions generated by stationary sources of air pollution.
2. Describe six principles used to control particulate emissions from stationary sources.
3. Explain how industry determines which type of control technology is appropriate and/or required.
4. Distinguish between methods of controlling emissions that require a control device and those that do not in the control of pollutant emissions.
5. List the types of devices used to control particulate emissions.
6. Describe the factors that affect collection efficiency.
7. Discuss the influence of particle size and composition on collection efficiency.
8. Recognize the structure of settling chambers and cyclones and describe how they collect particulate matter.
9. Recognize the structure of wet collectors used to control particulate matter and describe their operation.
10. Recognize the structure of electrostatic precipitators and describe their operation.
11. Recognize the structure of fabric filtration systems (baghouses), describe their operation, and list at least three methods of bag cleaning.

Reading Assignment: Godish, Thad, "Control of Emissions from Stationary Sources," *Air* Quality, 3rd Edition, New York: Lewis, 1997, pp. 309-340.

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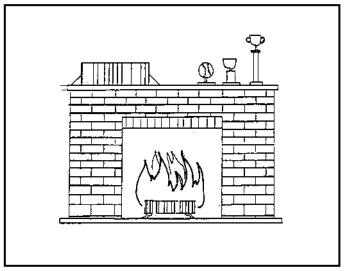
Control of Stationary Sources, Particulate Matter

Most of the air pollution produced by stationary sources results from the incomplete combustion of fuel or industrial processing.

The types of inorganic and organic air pollutants stationary sources emit are dependent on the specific process operations. For example, in 1993, stationary source fuel combustion accounted for 34.2% of all air pollution, second only to mobile sources, which contributed 56.2% (Godish, 1997). Fossil fuel fired boilers emit ash, sulfur dioxide, nitrogen oxides and mercury, and or vanadium if contained in the fuel. Certain boiler firing conditions can also produce "cenospheres," which are light hollow spheres that can be coated with unburned carbon.



The carbon can adsorb sulfur trioxide (SO_3) and water to form sulfuric acid ($H_2 SO_4$). Metallurgical plants can emit a variety of metal dusts, including iron oxides and sometimes fluorides and chlorides. Industrial plants manufacturing inorganic chemicals will emit various waste gases depending on their product. Odorous organic waste gases can also be emitted from organochemical and petrochemical plants. Industrial pollutant sources such as these and others can be categorized into several groups based on their specific process operation:

- *Process Operations.* Process operations with incomplete chemical reactions, which include combustion due to unconverted reactants, or a reaction having a final yield that is less than expected theoretical conversion.

- *Atmospheric Releases.* Atmospheric releases of a process's secondary components or impurities of raw materials.

- *Auxiliary Losses.* The auxiliary losses of compounds such as volatile organic solvents from fugitive sources or inorganics such as carbon disulfide and hydrogen sulfide in rayon production and fluorine compounds as in the production of aluminum.

- *Waste Emissions.* Emissions of malodorous substances or oxidation compounds in the exhaust from oxidation, heating or drying processes.

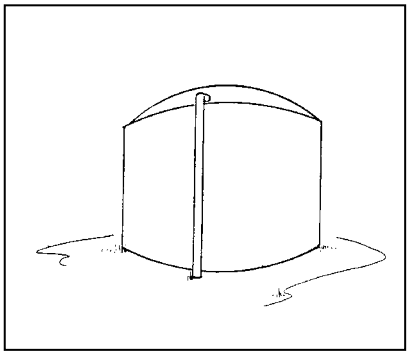
Releases from these categories can originate from a variety of emission points and may not be centrally collected before entering the atmosphere. Each category and source should be individually evaluated to determine what amount of the air contaminant is being emitted and what appropriate control strategy might be required.

Stack, duct, vent, fugitive and area sources are examples of industrial air release emission points.

Air release emission points, from industrial process operations, can be categorized as stack, duct, vent, fugitive and area (see Table 9-1). Fugitive emission points are release points, which are unconfined in a stack or duct before reaching the atmosphere. Therefore, whether an emission source is considered a point or fugitive source is dependant on whether the release is confined or unconfined in a stack or duct prior to atmospheric release.

Table 9-1. Industrial Process Operation Air Emission Points and Categories (Cheremisinoff, P.N., 1991)

Industrial Process Operation Air Emission Points and Categories	
Process Operation Reactors vents Distillation systems Vacuum systems Combustion stacks Blow molding Spray drying and booths Extrusion machines	**Fugitive Sources** Valves Pump seals Flanges/connectors Compressors Open ended lines Pressure relief devices Equipment cleaning/maintenance
Surface Area Sources Pond evaporation Cooling tower evaporation Wastewater treatment Land disposal	**Handling, Storage, Loading** Storage tank breathing losses Loading/unloading Line venting Packaging and container loading

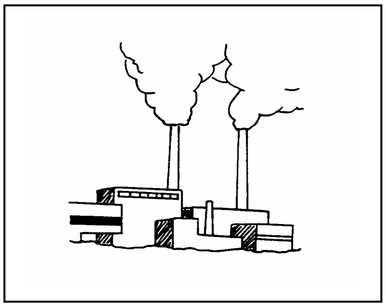


While stationary sources account for a tremendous amount of ambient air pollution, the control of these sources is a sensitive issue because these industries generate thousands of useful consumer products, create millions of jobs, and provide essential goods and services. Although it is necessary to control pollution from stationary sources, creating an economic environment that forces facilities out of the marketplace is not practical. Therefore, a fine balance must be achieved between the costs borne by industry and the protection of human health and the environment. The U.S. EPA believes that pollution control can be achieved through common sense solutions such as the installation of effective control technology, changes in production processes, and the implementation of pollution prevention techniques.

Compliance with emission standards and the successful attainment of air quality standards depends in large part on the application of appropriate stationary source control measures. Although stationary source emissions vary greatly, in quantity and character, applying responsible control practices can reduce their effects. The purpose of this chapter is to review the principles and practices of stationary source emission control.

Control Procedures

The control of stationary source emissions can be accomplished through the application of a sound control strategy. The control strategy required for an industrial environmental impact is a four step process: (1) elimination of the problem source or operation, (2) modification of the source operation, (3) relocation of the source, and (4) selection and application of the appropriate control technology.



Control procedures for stationary sources of pollution include the use of tall smokestacks, changes in plant operations, and installation of effective control devices.

Some of the strategies used to control particulate and gaseous emissions may also include the use of well-planned tall stacks.

Elevated exhaust stacks reduce the exposure of surrounding populations to concentrated pollutants.

Exhaust Stacks. Exhaust stacks do not reduce emissions from a stationary source; rather they reduce the local effects of the pollution by elevating the exhaust stream to a point where it can be more effectively dispersed. High exhaust stacks were an inexpensive solution in the absence of expensive control technology. For years elevated stacks were used with the nearby communities in mind. A belief was widely held that elevated stacks reduced the likelihood that pollutants would have any effect on neighboring populations. Utility and smelter operations have traditionally used tall stacks (200m to 400m) in order to reduce the amount of ground-level concentrations of sulfur dioxide (SO_2). Plumes from higher stacks were diluted and dispersed by natural forces such as ambient air currents. So the purpose of tall stacks was to disperse as much of the pollutant as possible over as wide an area as possible. However, this did not always eliminate the problem, but instead simply transferred it to another location (Godish, 1997).

This approach was used for many years, until concern arose over the regional and transboundary spread of harmful toxics. For example, there is great concern over the spread of acid rain from one region to another, particularly across political borders. These issues are the current topics of discussion between the United States, Canada, and European countries.

Plant Operations. Compliance with emission standards may require the use of control technology, but many industrial operations have reduced emissions by changing operational methods. Some of these changes include pre-treating process materials, fuel or material substitution, and changes in the manufacturing process. As an example of how pre-treating raw materials can be an inexpensive solution to pollution control, industry has discovered that significant reductions in particulate matter and sulfur emissions can be achieved by a technique called coal washing. Pre-treating raw materials in this manner not only reduces the amount of fly ash released from coal, but it also reduces the amount of inorganic sulfur released as well.

Another way to comply with emission standards is to substitute cleaner fuels during the refining process. Natural gas and low-sulfur fuel oil are just two examples of fuels that emit less pollution during combustion. However, cleaner fuels can be more expensive and can increase national reliance on foreign fuel sources.

Reduction in emissions from stationary sources can also be accomplished through increased attention to plant maintenance. Plants that release significant quantities of pollutants into the environment frequently do so as the result of improperly maintained equipment. This is especially true of combustion equipment. Adequately scheduled maintenance must be performed to reduce both the exhaust and amount of fugitive emissions released from vats, valves, and transmission lines. Periodic maintenance also reduces the likelihood of spill-related accidents by discovering faulty equipment before problems occur (Godish, 1997).

Control Technology. A final way to reduce emissions from stationary sources is through the use of advanced, add-on control technology. Control devices can destroy or recover gaseous compounds or particulate matter for proper disposal or re-use. The pollution control operations used to destroy or capture gases include combustion, adsorption, absorption, and condensation. Control devices that implement these processes include thermal incinerators, catalytic incinerators, flares, boilers, process heaters, carbon absorbers, spray towers, and surface condensers.

Add-on equipment may be installed to destroy or recover pollutants for proper disposal.

The most important process parameters for selecting air pollution control equipment are the exhaust gas characteristics obtained from emissions tests and process or site characteristics obtained from a field survey.

Exhaust Gas Characteristics

- Total exhaust gas flow rate
- Exhaust gas temperature
- Required control efficiency
- Particle size distribution
- Particle resistivity
- Composition of emissions
- Corrosiveness of exhaust gas over operating range
- Moisture content
- Stack pressure
- Exhaust gas combustibility and flammability properties

Process or Site Characteristics

- Reuse/recycling of collected emissions
- Availability of space
- Availability of additional electrical power
- Availability of water
- Availability of wastewater treatment facilities
- Frequency of startup and shutdowns
- Environmental conditions
- Anticipated changes in control regulations
- Anticipated changes in raw materials
- Plant type – stationary or mobile

Technologies used to control particulate matter focus on removing particles from the effluent gas stream. Many factors (such as particle size and chemical characteristics) determine the appropriate particulate control device for a process. Devices most commonly used to control particulate matter include electrostatic precipitators, fabric filters, venturi scrubbers, cyclone collectors, and settling chambers. The following section provides a more detailed discussion of each type of control technology used for both particulate and gaseous emissions (Godish, 1997).

Control Devices for Particulate Emissions

Particulate matter is any finely divided liquid or solid substance. Examples of particulate matter include smoke, dust, or some forms of fine mist and is entrained in effluent gas streams or suspended in ambient air. Any particulate less than 10 micrometers (μm) in diameter is defined as PM_{10} and is regulated as a criteria pollutant. The purpose of such regulation is to control smaller, respirable particles that can bypass the body's respiratory filters and penetrate deeply into the lungs, which could cause harm to human health. Toxic substances, such as sulfates, sulfites, nitrates, heavy metals, and polycyclic organic matter are predominantly carried by particles in this size range. Therefore, control devices used today, to prevent particles from reaching the ambient air, focus on capturing particulate matter $\leq$10μm in diameter.

Devices most commonly used devices to control particulate emissions include:

- *Electrostatic Precipitation*
- *Fabric Filters*
- *Venturi Scrubbers*
- *Cyclones*
- *Settling Chambers*

Several factors must be considered when selecting an appropriate particulate control device. Typically, particles must be captured from an effluent gas stream; therefore, characteristics of the particles and the gas stream will determine the appropriate control device. Characteristics that must be considered include the particle size and resistivity, exhaust flow rate, temperature, moisture content, and various chemical properties of the exhaust stream such as explosiveness, acidity, alkalinity, and flammability. For example, although the electrostatic precipitator has a 99 percent removal efficiency for most particles less than 10µm, it would be a disastrous selection for any exhaust stream that contains high levels of volatile organic compounds (VOCs). Exposing a highly explosive, volatile substance to a control device that relies primarily on electrical charge would be a dangerous and inappropriate use of technology.

In many cases, a combination of multiple devices yields the best collection efficiency. For example, a settling chamber can be used to remove large particles from the exhaust stream before it enters an electrostatic precipitator where smaller particles are removed. [The following control devices are most commonly used to regulate the flow of particulate matter into the ambient air.] The devices most commonly used to control particulate emissions include fabric filters, venturi scrubbers, cyclones, electrostatic precipitators, and settling chambers.

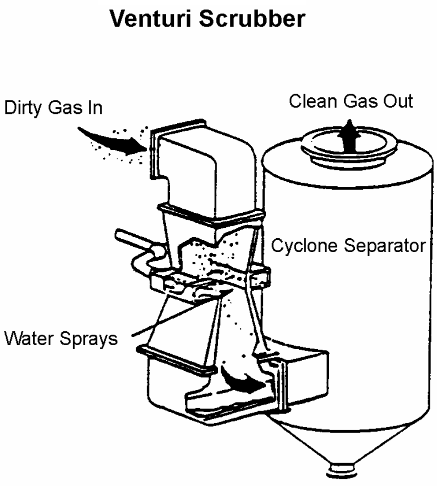


Figure 9-1. Venturi Scrubber

The Venturi scrubber uses wet impingement to trap gas-laden particles in a liquid form.

Venturi Scrubbers. Venturi scrubbers use a liquid stream to remove solid particles, as shown in Figure 9-1. A venturi scrubber accelerates the waste gas stream to atomize the scrubbing liquid and to improve gas-liquid contact. In a venturi scrubber, a “throat” section is built into the duct that forces the gas stream to accelerate as the duct narrows and then expands. As the gas enters the venturi throat, both gas velocity and turbulence increase. Depending on the scrubber design, the scrubbing liquid is sprayed into the gas stream before the gas encounters the venturi throat, or in the throat, or upwards against the gas flow in the throat. The scrubbing liquid is then atomized into small droplets by the turbulence in the throat and droplet-particle interaction is increased. Some designs use supplemental hydraulically or pneumatically atomized sprays to augment droplet creation. However, the disadvantage of these designs is that clean liquid feed is required to avoid clogging (EPA, 1998; AWMA, 1992; Corbitt, 1990).

After the throat section, the mixture decelerates, and further impacts occur causing the droplets to agglomerate. Once the particles are captured by the liquid, the wetted PM and excess liquid droplets are then separated from the gas stream by an entrainment section, which usually consists of a cyclonic separator and/or a mist eliminator (EPA, 1998; Corbitt, 1990).

Current designs for venturi scrubbers generally use the vertical downflow of gas through the venturi throat and incorporate three features: (1) a “wet-approach” or “flooded-wall” entry section to avoid a dust buildup at a wet-dry junction; (2) an adjustable throat for the venturi throat to provide for adjustment of the gas velocity and the pressure drop; and (3) a “flooded” elbow located below the venturi and ahead of the entrainment separator, to reduce wear by abrasive particles. The venturi throat is also sometimes fitted with a refractory lining to resist abrasion by dust particles (Perry, 1984).

Typical gas flow rates for a single-throat venturi scrubber unit are 0.2 to 28 standard cubic meters per second (sm^3 /sec) (500 to 60,000 standard cubic feet per minute (scfm). Flows higher then this range will use either multiple venturi scrubbers in parallel or a multiple throated venturi (Cooper, 1994; EPA, 1998; AWMA, 1992).

Particle collection efficiencies of venturi scrubbers range from 70 to greater than 99 percent, depending on the application. Collection efficiencies are generally higher for PM with aerodynamic diameters of approximately 0.5 to 5μm. Some venturi scrubbers are designed with an adjustable throat to control the velocity of the gas stream and the pressure drop. Increasing the venturi scrubber efficiency requires increasing the pressure drop, which in turn increases the energy consumption (Corbitt, 1990; EPA, 1998).

Particle collection efficiencies of venturi scrubbers range from 70 to greater than 99 percent, depending on the application.

Venturi scrubbers have been applied to control PM emissions from utility, industrial, commercial, and institutional boilers fired with coal, oil, wood, and liquid waste. They have also been applied to control emission sources in the chemical, mineral products, wood, pulp and paper, rock products, and asphalt manufacturing industries, lead, aluminum, iron and steel, and gray iron production industries; and to municipal solid waste incinerators. Typically, venturi scrubbers are applied where it is necessary to obtain high collection efficiencies for fine PM. Thus, they are applicable to controlling emission sources with high concentrations of submicron PM (EPA, 1995; Turner, 1999).

Typically, venturi scrubbers are applied where it is necessary to obtain high collection efficiencies for fine PM. Thus, they are applicable to controlling emission sources with high concentrations of submicron PM.

For PM applications, wet scrubbers generate waste in the form of a slurry or wet sludge. This creates the need for both wastewater treatment and solid waste disposal. Initially, the slurry is treated to separate the solid waste from the water. The treated water can then be reused or discharged. However, once the water is removed, the remaining waste will be in the form of a solid or sludge. If the solid waste is inert and nontoxic, it can generally be landfilled. Hazardous wastes will have more stringent procedures for disposal. In some cases, the solid waste may have value and can be sold or recycled (EPA, 1998).

Advantages of Venturi Scrubbers (Cooper, 1994)

- Capable of handling flammable and explosive dusts
- Can handle mists in process exhausts
- Relatively low maintenance
- Simple in design and easy to install
- Collection efficiency can be varied
- Provides cooling for hot gases
- Neutralizes corrosive gases and dusts

Disadvantages of Scrubbers (Perry, 1984, Cooper, 1994)

- Effluent liquid can create water pollution problems
- Waste product collected wet
- High potential for corrosion problems
- Requires protection against freezing
- Final exhaust gas requires reheating to avoid visible plume
- Collected PM may be contaminated, and not recyclable
- Disposal of waste sludge may be very expensive

Electrostatic precipitators. An ESP is a PM control device that uses electrical forces to move particles entrained within an exhaust stream onto collection surfaces. The entrained particles are given an electrical charge when they pass through a corona, a region where gaseous ions flow. Electrodes in the center of the flow lane are maintained at high voltage and generate the electrical field that forces the particles to the collector plates. The high voltage electrodes are long wires or rigid "masts" suspended from a frame in the upper part of the ESP that run through the axis of each tube. Rigid electrodes are generally supported by both an upper and lower frame. In modern designs, sharp points are added to the electrodes, either at the entrance to a tube or along the entire length in the form of stars to provide additional ionization sites (EPA, 1998; Flynn, 1999).

Particulate matter is removed from Electrostatic Precipitators by mechanical "rapping," wet wash, or acoustic blast.

The power supplies for the ESP convert the industrial AC voltage (220 to 480 volts) to pulsating DC voltage in the range of 20,000 to 100,000 volts as needed. The voltage applied to the electrodes causes the gas between the electrodes to break down electrically, an action known as a "corona." The electrodes are usually given a negative polarity because a negative corona supports a higher voltage than does a positive corona before sparking occurs. The ions generated in the corona follow electric field lines from the electrode to the collecting pipe. Therefore, each electrode-pipe combination establishes a charging zone through which the particles must pass. As larger particles (>10µm diameter) absorb many times more ions than small particles (>1µm diameter), the electrical forces are much stronger on the large particles (EPA, 1996).

When the collection plates are filled to capacity, the particulate is removed from the plates by "rapping," which is a mechanical means to dislodge the particulate. The collected particulate material slides downward into a hopper located below the unit.

Recently, dry wire-pipe ESPs are being cleaned acoustically with sonic horns (Flynn, 1999). The horns, typically cast metal horn bells, are usually powered by compressed air. The acoustic vibration is introduced by a vibrating metal plate, which periodically interrupts the airflow (AWMA, 1992). As with a rapping system, the collected particulate slides downward into the hopper. The hopper is evacuated periodically as it becomes full. Dust is removed through a valve into a dust-handling system, such as a pneumatic conveyor, and is then disposed of in an appropriate manner.

In wet ESPs, the collectors are either intermittently or continuously washed by a spray of liquid, usually water. The collection hoppers used by dry ESPs are replaced with a drainage system. The wet effluent is collected, and often treated on-site (EPA, 1998). In a wire-pipe ESP, also called a tubular ESP, the exhaust gas flows vertically through conductive tubes, generally with many tubes operating in parallel. The tubes may be formed as a circular, square, or hexagonal honeycomb. Square and hexagonal pipes can be packed closer together than cylindrical pipes, reducing wasted space. Pipes are generally 7 to 30 cm (3 to 12 inches (in.) in diameter and 1 to 4 m (3 to 12 feet) in length.

Wet ESPs require a source of wash water to be injected or sprayed near the top of the collector pipes either continuously or at timed intervals. This wash system replaces the rapping mechanism generally used by dry ESPs. The water flows with the collected particles into a sump from which the fluid is pumped or drained. A portion of the fluid may be recycled to reduce the total amount of water required. The remainder is pumped into a settling pond or passed through a dewatering stage, with subsequent disposal of the sludge (AWMA, 1992).

Wet wire-pipe ESPs, and other ESPs in general, have very low-pressure drops (typically less than 13 millimeters [0.5 in.] water column) because they act only on the particulate to be removed, and only minimally hinder flue gas flow. As a result, energy requirements and operating costs tend to be low. They are capable of very high efficiencies, even for very small particles. Operating costs are also relatively low. ESPs are capable of operating under high pressure (1,030 kPa [150 psi]) or vacuum conditions, and relatively large gas flow rates can be effectively handled (AWMA, 1992). Wet ESPs can collect sticky particles and mists, as well as highly resistive or explosive dusts. The continuous or intermittent washing with a liquid eliminates the re-entrainment of particles due to rapping, which dry ESPs cannot effectively control. The humid atmosphere that results from the washing in a wet ESP enables them to collect high resistivity particles, absorb gases or cause pollutants to condense and cool, and condition the gas stream.

Liquid particles or aerosols present in the gas stream are collected along with solid particles and provide another means of rinsing the collection electrodes (EPA, 1998). Wet wire-pipe ESPs have the additional advantages of reducing “sneakage” by passing the entire gas stream through the collection field. The wet wire-pipe ESPs ability to be tightly sealed to prevent leaks of material is an especially valuable feature for hazardous materials (AWMA, 1992).

The collection efficiency of an ESP is quite reliably about 99 percent for particles less than 10 micrometers.

The collection efficiency of an ESP is quite reliably about 99 percent for particles less than 10μm. Wire-Plate Type Typical new equipment design efficiencies are between 99 and 99.9%, while older existing equipment has a range of actual operating efficiencies of 90 to 99.9%. Although several factors determine ESP collection efficiency, ESP size is the most important. Size determines treatment time. The longer a particle spends in the ESP, the greater will be its chance of being collected. Maximizing electric field strength will effectively maximize ESP collection efficiency (STAPPA/ALAPCO, 1996). Collection efficiency is also affected by dust resistivity, gas temperature, chemical composition (of the dust and the gas), and particle size distribution. Cumulative collection efficiencies of PM, PM_{10}, and $PM_{2.5}$ for actual operating ESPs in various types of applications are presented in Table 9-2.

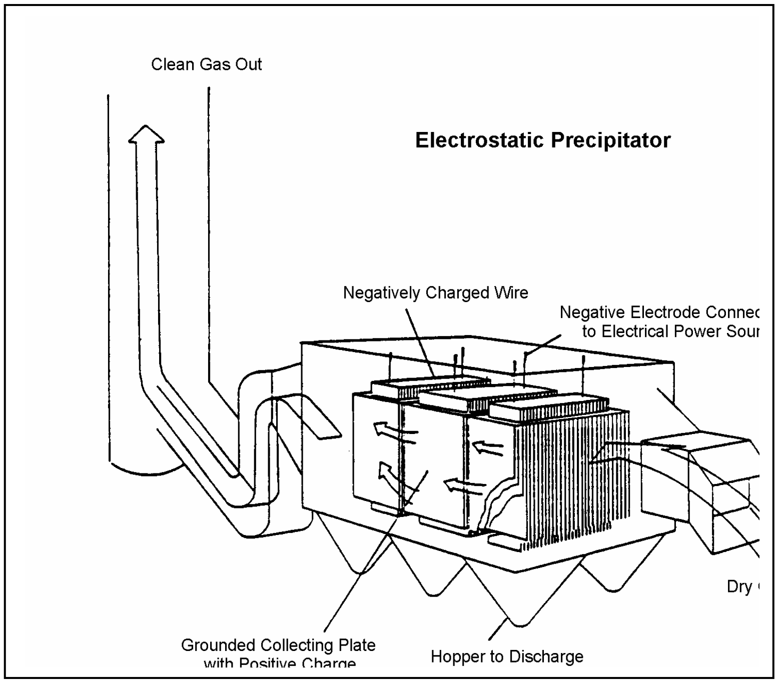
ESPs, in general, are very expensive to operate and are not very well suited for use in industrial processes because they are too sensitive to fluctuations in the gas stream.

Wire-Pipe Type ESPs generally have high capital costs. Wire discharge electrodes (approximately 2.5 mm [0.01 in.] in diameter) are high-maintenance items. Corrosion can occur near the top of the wires because of air leakage and acid condensation. Also, long weighted wires tend to oscillate – the middle of the wire can approach the pipe, causing increased sparking and wear. Newer ESP designs tend toward rigid electrodes, or “masts” which largely eliminate the drawbacks of using wire electrodes (Cooper and Alley, 1994; Flynn, 1999). ESPs in general are not suited for use in processes, which are highly variable because they are very sensitive to fluctuations in gas stream conditions (flow rates, temperatures, particulate and gas composition, and particulate loadings).

Table 9-2. Cumulative PM, PM_{10}, and $PM_{2.5}$ Collection Efficiencies for Dry ESPs (EPA, 1998; EPA, 1997)

Application	Collection Efficiency (%)		
	Total PM	PM_{10}	$PM_{2.5}$
Coal-Fired Boilers			
Dry bottom bituminous)	99.2	97.7	96.0
Spreader stoker (bituminous)	99.2	99.4	97.7
Primary Copper Production			
Multiple hearth roaster	99.0	99.0	99.1
Reverbatory smelter	99.0	97.1	97.4
Iron and Steel Production			
Open hearth furnace	99.2	99.2	99.2

ESPs are also difficult to install in sites, which have limited space, since ESPs must be relatively large to obtain the low gas velocities necessary for efficient PM collection



(Cooper and Alley, 1994). Relatively sophisticated maintenance personnel are required, as well as special precautions to safeguard personnel from the high voltage. The high voltage also produces ozone molecules from the negatively charged electrodes during gas ionization (AWMA, 1992). Wet ESPs add to the complexity of a wash system, and the fact that the resulting slurry must be handled more carefully than a dry product, and in many cases requires treatment, especially if the dust can be sold or recycled.

Wet ESPs are limited to operating at stream temperatures under approximately 80° to 90ºC (170° to 190ºF), and generally must be constructed of non-corrosive materials (EPA, 1998; Flynn, 1999). For wet ESPs, consideration must be given to handling wastewaters. For simple systems with innocuous dusts, water with particles collected by the ESP may be discharged from the ESP system to a solids-removing clarifier (either dedicated to the ESP or part of the plant wastewater treatment system) and then to final disposal. More complicated systems may require skimming and sludge removal, clarification in dedicated equipment, pH adjustment, and/or treatment to remove dissolved solids. Spray water from an ESP preconditioner may be treated separately from the water used to wash the ESP collecting pipes so that the cleaner of the two treated water streams may be returned to the ESP. Recirculation of treated water to the ESP may approach 100 percent (AWMA, 1992).

The Electrostatic Precipitator (ESP) separates particles from the gas stream by electrically charging the particles.

Dusts with very high resistivities (greater than 10^{10} ohm-cm) are also not well suited for collection in dry ESPs. These particles are not easily charged, and thus are not easily collected. High-resistivity particles also form ash layers with very high voltage gradients on the collecting electrodes. Electrical breakdowns in these ash layers lead to injection of positively charged ions into the space between the discharge and collecting electrodes (back corona), thus reducing the charge on particles in this space and lowered collection efficiency. Fly ash from the combustion of low-sulfur coal typically has a high resistivity, and thus is difficult to collect (ICAC, 1999).

In a fabric filter, flue gas is passed through a tightly woven or felted fabric, causing PM in the flue gas to be collected on the fabric by sieving and other mechanisms.

Fabric filters. In a fabric filter, flue gas is passed through a tightly woven or felted fabric, causing PM in the flue gas to be collected on the fabric by sieving and other mechanisms. Fabric filters may be in the form of sheets, cartridges, or bags, with a number of the individual fabric filter units housed together in a group. Bags are the most common type of fabric filter.

The dust cake that forms on the filter from the collected PM can significantly increase collection efficiency. Fabric filters are frequently referred to as baghouses because the fabric is usually configured in cylindrical bags. Bags may be 6 to 9m (20 to 30 ft) long and 12.7 to 30.5 centimeters (cm) (5 to 12 inches) in diameter. Groups of bags are placed in isolable compartments to allow cleaning of the bags or replacement of some of the bags without shutting down the entire fabric filter (STAPPA/ALAPCO, 1996). Operating conditions are important determinants of the choice of fabric. Some fabrics (i.e., polyolefins, nylons, acrylics, polyesters) are useful only at relatively low temperatures of 95° to 150ºC (200° to 300ºF). For high-temperature flue gas streams, more thermally stable fabrics such as fiberglass, Teflon®, or Nomex® must be used (STAPPA/ALAPCO, 1996).

The practical application of fabric filters requires the use of a large fabric area in order to avoid an unacceptable pressure drop across the fabric. Baghouse size for a particular unit is determined by the choice of air-to-cloth ratio, or the ratio of volumetric airflow to cloth area. The selection of air-to-cloth ratio depends on the particulate loading and characteristics, and the cleaning method used. A high particulate loading will require the use of a larger baghouse in order to avoid forming too heavy a dust cake, which would result in an excessive pressure drop. As an example, a baghouse for a 250-megawatt (MW) utility boiler may have 5,000 separate bags with a total fabric area approaching 46,500 m^2 (500,000 square feet) (ICAC, 1999).

Determinants of baghouse performance include the fabric chosen, the cleaning frequency and methods, and the particulate characteristics. Fabrics can be chosen which will intercept a greater fraction of particulate. In order to accomplish this, some fabrics are coated with a membrane of very fine openings for enhanced removal of submicron particulate. However, such fabrics tend to be more expensive. Cleaning intensity and frequency are important variables in determining removal efficiency because the dust cake can affect the fine particulate removal capability of a fabric. Cleaning procedures, which may be too frequent or too intense, will also lower the removal efficiency of the fabric filter. On the other hand, if removal is too infrequent or too ineffective, then the baghouse pressure drop will become too high (ICAC, 1999).

Mechanical shaking of bags has been a popular cleaning method for many years because of its simplicity as well as its effectiveness.

Mechanical shaking of the bags has been a popular cleaning method for many years because of its simplicity as well as its effectiveness. In a typical operation, dusty gas enters an inlet pipe to the shaker. Very large particles are removed from the stream when they strike the baffle plate in the inlet duct and fall into the hopper. The particulate-laden gas is drawn from beneath a cell plate in the floor and into the filter bags. The gas proceeds from the inside of the bags to the outside and through the outlet pipe. The particles are collected on the inside surface of the bags and a filter cake accumulates. In mechanical shaking units, the tops of bags are attached to a shaker bar, which is moved briskly (usually in a horizontal direction) to clean the bags. The shaker bars are operated by mechanical motors or by hand, in applications where cleaning is not required frequently (EPA, 1998).

Reverse-air cleaning is another popular fabric filter cleaning method that has been used extensively and improved over the years. It is a gentler but sometimes less effective cleaning mechanism than mechanical shaking. Most reverse-air fabric filters operate in a manner similar to shaker-cleaned fabric filters. Typically, the bags are open on bottom, closed on top, and the gas flows from the inside to the outside of the bags with dust being captured on the inside. However, some reverse-air designs collect dust on the outside of the bags.

In either design, forcing clean air through the filters in the opposite direction of the dusty gas flow performs reverse-air cleaning. The change in direction of the gas flow causes the bag to flex and crack the filter cake. In internal cake collection, the bags are allowed to collapse to some extent during reverse-air cleaning. The bags are usually prevented from collapsing entirely by some kind of support, such as rings that are sewn into the bags. The support enables the dust cake to fall off the bags and into the hopper. Cake release is also aided by the reverse flow of the gas because felted fabrics retain dust more than woven fabrics. Therefore, they are more difficult to clean. For this reason, felts are usually not used in reverse-air systems (EPA, 1998).

There are several methods of reversing the flow through the filters. As with mechanical shaker-cleaned fabric filters, the most common approach is to have separate compartments within the fabric filter so that each compartment can be isolated and cleaned separately while the other compartments continue to treat the dusty gas. One method of providing the reverse flow air is by the use of a secondary fan or cleaned gas from the other compartments.

Reverse-air cleaning alone is used only in cases where the dust releases easily from the fabric. In many instances, reverse-air is used in conjunction with shaking, pulsing or sonic horns (EPA, 1998). Sonic horns are being increasingly used to enhance the collection efficiency of mechanical shaker and reverse-air fabric filters (AWMA, 1992). Sonic horns use compressed air to vibrate a metal diaphragm, producing a low frequency sound wave from the horn bell. The number of horns required is determined by the fabric area and the number of baghouse compartments.

Typically, 1 to 4 horns per compartment operating at 150 to 200 hertz are required. Compressed air to power the horns is supplied at 275 to 620 kiloPascals (kPa) (40 to 90 pounds per square inch gage [psig]). Sonic horns activate for roughly 10 to 30 seconds during each cleaning cycle (Carr, 1984). Sonic horn cleaning significantly reduces the residual dust load on the bags, which decreases the pressure drop across the filter fabric by 20 to 60 percent. It also lessens the mechanical stress on the bags, resulting in longer operational

The Baghouse removes particulate matter by forcing contaminated air through a series of fabric filters, much like the filtering action of a vacuum cleaner.

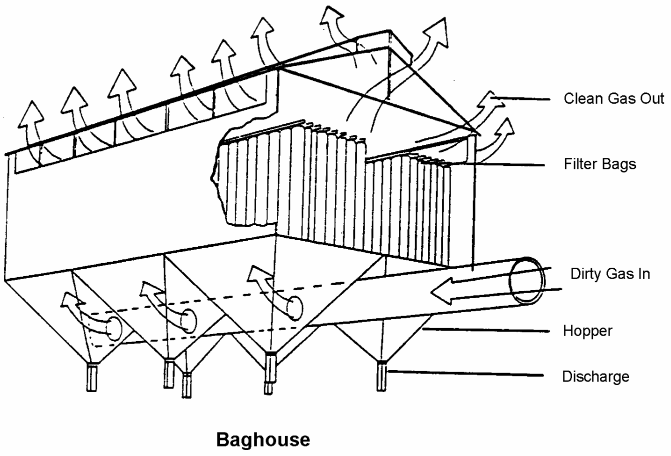


Figure 9-3. Fabric Filter

life (Carr, 1984). As stated previously, this can decrease the O&M cost by 1 to 3%, annually.

Baghouse compartments are easily retrofitted with sonic horns and are frequently used with fabric filters at coal-burning utilities (EPA, 1998). Reverse-jet is another cleaning method developed in the 1950s to provide better removal of residual dusts. In this method, the reverse air is piped to a ring around the bag with a narrow slot in it. The air flows through the slot, creating a high velocity air stream that flexes the bag at that point. The ring is mounted on a carriage, driven by a motor and cable system that travels up and down the bag. This method provides an excellent way to clean residual dust. However, due to its complexity, maintenance requirements are high. In addition, air impingement on the bags results in increased wear (Billings, 1970). Therefore, the use of reverse-jet cleaning procedures has been declining in recent years (EPA, 1998).

Pulse-jet cleaning of fabric filters is a relatively new concept as compared to other types of fabric filters; they have been used only in the past 30 years. However, this cleaning mechanism has consistently grown in popularity because it can treat high dust loadings, operate at constant pressure drop, and occupy less space than other types of fabric filters. Pulse-jet cleaned fabric filters can only operate as external cake collection devices. The bags are closed at the bottom, open at the top, and supported by internal retainers called cages. Particulate-laden gas flows into the bag, with diffusers often used to prevent oversized particles from damaging the bags. The gas flows from the outside to the inside of the bags, and then out the gas exhaust. The particles are then collected on the outside of the bags and drop into a hopper below the fabric filter (EPA, 1998).

During pulse-jet cleaning, a short burst of air is injected into the bags. The wave of air flexes the fabric, pushing it away from the cage, and then snaps it back dislodging the particulate matter.

During pulse-jet cleaning, a short burst of air, 0.03 to 0.1 seconds in duration, of high pressure [415 to 830 kiloPascals (kPa) (60 to 120 pounds per square inch gage [psig]) air is injected into the bags (EPA, 1998; AWMA, 1992). A remote timer connected to a solenoid controls this cleaning cycle air. The pulse is then blown through a venturi nozzle at the top of the bags and establishes a shock wave that continues onto the bottom of the bag. The wave flexes the fabric, pushing it away from the cage, and then snaps it back dislodging the dust cake. The burst of air is controlled by the solenoid valve and is released into blow pipes that have nozzles located above the bags. The bags are usually cleaned row by row (EPA, 1998).

There are several unique attributes of pulse-jet cleaning. Because the cleaning pulse is very brief, the flow of dusty gas does not have to be stopped during cleaning. The other bags continue to filter, taking on extra duty when other bags are cleaned. In general, there is no change in fabric filter pressure drop or performance as a result of pulse-jet cleaning. This enables the pulse-jet fabric filters to operate on a continuous basis with solenoid valves as the only significant moving parts. Pulse-jet cleaning is also more intense and occurs with greater frequency than the other fabric filter cleaning methods. This intense cleaning dislodges nearly all of the dust cake each time the bag is pulsed. As a result, pulse-jet filters do not rely on a dust cake to provide filtration. Felted (non-woven) fabrics are used in pulse-jet fabric filters because they do not require a dust cake to achieve high collection efficiencies. However, it has been found that woven fabrics used with pulse-jet fabric filters leak a great deal of dust after they are cleaned (EPA, 1998).

Since bags cleaned by the pulse-jet method do not need to be isolated for cleaning, pulse-jet cleaned fabric filters do not need extra compartments to maintain adequate filtration during cleaning. Also, because of the intense and frequent nature of the cleaning, they can treat higher gas flow rates with higher dust loadings. Consequently, fabric filters cleaned by the pulse-jet method can be smaller than other types of fabric filters in the treatment of the same amount of gas and dust, making higher gas-to-cloth ratios achievable (EPA, 1998).

Fabric filters in general provide high collection efficiencies on both coarse and fine (submicron) particulates. Typical new equipment design efficiencies are between 99% and 99.9%.

Fabric filters in general provide high collection efficiencies on both coarse and fine (submicron) particulates. Typical new equipment design efficiencies are between 99 and 99.9%. Older existing equipment has a range of actual operating efficiencies of 95 to 99.9%. Several factors determine fabric filter collection efficiency which include gas filtration velocity, particle characteristics, fabric characteristics, and cleaning mechanism. In general, collection efficiency increases with increased filtration velocity and particle size. For a given combination of filter design and dust, the effluent particle concentration from a fabric filter is nearly constant, whereas the overall efficiency is more likely to vary with particulate loading. For this reason, fabric filters can be considered to be constant outlet devices rather than constant efficiency devices.

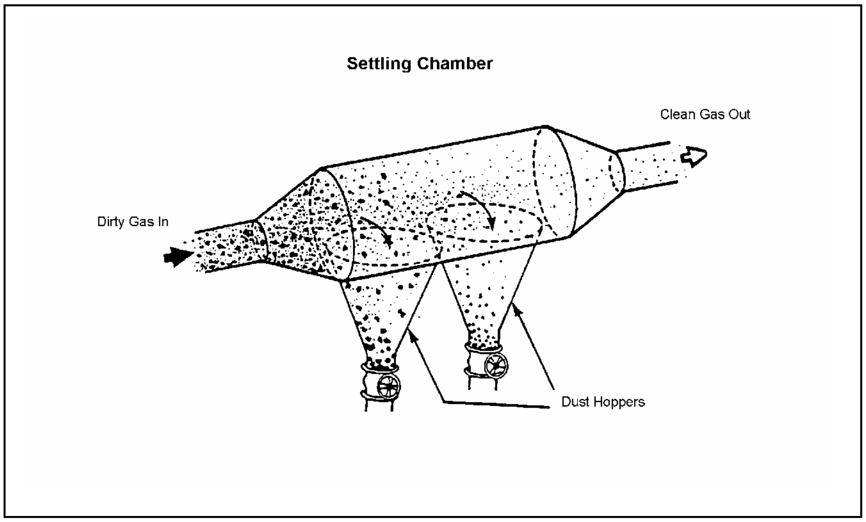
Constant effluent concentration is achieved because at any given time, part of the fabric filter is being cleaned. As a result of the cleaning mechanisms used in fabric filters, the collection efficiency is constantly changing. Each cleaning cycle removes at least some of the filter cake and loosens particles, which remain on the filter. When filtration resumes, the filtering capability has been reduced because the lost filter cake and loose particles are pushed through the filter by the flow of gas. As particles are captured, the efficiency increases until the next cleaning cycle. Average collection efficiencies for fabric filters are usually determined from tests that cover a number of cleaning cycles at a constant inlet loading (EPA, 1998).

Fabric filters are relatively insensitive to fluctuations in gas stream conditions. Efficiency and pressure drop are relatively unaffected by large changes in inlet dust loadings for continuously cleaned filters. Filter outlet air is very clean and may be recirculated within the plant in many cases (for energy conservation). Collected material is gathered in a dry form for subsequent processing or disposal. Corrosion and rusting of components are usually not problems.

The operation of baghouses is relatively simple. Unlike electrostatic precipitators, fabric filter systems do not require the use of high voltage; therefore, maintenance is simplified and flammable dust may be collected with proper care. The use of selected fibrous or granular filter aids (precoating) permits the high-efficiency collection of submicron smokes and gaseous contaminants. Filter collectors are available in a large number of configurations, resulting in a range of dimensions and inlet and outlet flange locations to suit installation requirements (AWMA, 1992). Fabric filters are used for collecting particles with resistivities either too low or too high for collection with electrostatic precipitators. Fabric filters therefore may be a good candidate for collecting fly ash from low-sulfur coals or fly ash containing high unburned carbon levels, which respectively have high and low resistivities, and are thus relatively difficult to collect with electrostatic precipitators (STAPPA/ALAPCO, 1996).

Since settling chambers are most effective in removing only large particles, they are frequently used in combination with a control device that can effectively capture smaller particles.

Settling chambers. This type of technology is a part of the group of air pollution controls collectively referred to as "precleaners." They are referred to as precleaners because they are often used to reduce the inlet loading of particulate matter (PM) to downstream collection devices by removing larger, abrasive particles. Settling chambers are also referred to as gravity settling chambers, gravity collectors, expansion chambers, and outfall chambers. This is because settling chambers are quite effective in removing only large particles; therefore, they can be frequently used in combination with other control devices.



Settling Chambers rely on simple gravitation to remove particles from a gas stream.

Figure 9-4. Settling Chamber

Settling chambers, which rely on gravitational settling as a collection mechanism are the simplest and oldest mechanical collectors (see Figure 9-4). Settling chambers are generally built in the form of long, horizontal, rectangular chambers with an inlet at one end and an exit at the side or top of the opposite end. Flow within the chamber must be uniform and without any macroscopic mixing. Uniform flow is can be improved by flow straighteners at the inlet to the chamber. Hoppers are used to collect the settled-out material, though drag scrapers and screw conveyers have also been employed. The dust removal system must be sealed to prevent air from leaking into the chamber which increases turbulence, causes dust reentrainment, and prevents dust from being properly discharged from the device (EPA, 1982; Wark, 1981; Corbitt, 1990; Perry, 1984; Mycock, 1995; Avallone, 1996; EPA, 1998).

There are two primary types of settling chambers: the expansion chamber and the multiple-tray chamber. In the expansion chamber, the velocity of the gas stream is significantly reduced as the gas expands in a large chamber. The reduction in velocity allows larger particles to settle out of the gas stream (EPA, 1992; Wark, 1981; Perry, 1984; Mycock, 1995; EPA, 1998).

A multiple-tray settling chamber is an expansion chamber with a number of thin trays closely spaced within the chamber, which causes the gas to flow horizontally between them. While the gas velocity is increased slightly in a multiple-tray chamber, when compared to a simple expansion chamber, the collection efficiency generally improves because the particles have a much shorter distance to fall before they are collected. Multiple-tray settling chambers have lower volume requirements than expansion-type settling chambers for the collection of small particles (<15µm) (EPA, 1998).

The efficiency of settling chambers increases with the residence time of the waste gas in the chamber. Because of this, settling chambers are often operated at the lowest possible gas velocities. In reality, the gas velocity must be low enough to prevent dust from becoming reentrained, but not so low that the chamber becomes unreasonably large. The unit size is generally driven by the desired gas velocity within the unit, which should be less than 3 meters per second (m/s) (10 feet per second (ft/sec), and preferably less than 0.3 m/s (1 ft/sec) (Wark, 1981; Corbitt, 1990; Mycock, 1995; EPA, 1998).

Settling chambers are most effective when collecting large or dense particles, but often fail when the chamber becomes plugged with collected dust.

The most common failure of settling chambers is when chambers become plugged with collected dust. In expansion settling chambers the plugging can result from hopper bridging or hopper discharge seal failure. Multiple-tray settling chambers may experience plugging of the individual gas passages. Such failures can be prevented or minimized by use of hopper level indicators or by continuous monitoring of the dust discharge. Scheduled internal inspection can determine areas of air leakage and condensation, both of which may cause hopper bridging. Normal instrumentation for a settling chamber generally includes only an indicator of differential static pressure. An increase in static pressure drop can indicate plugging (EPA, 1992).

The collection efficiency of settling chambers varies as a function of particle size and settling chamber design. Settling chambers are most effective for large and/or dense particles. Gravitational force may be employed to remove particles where the settling velocity is greater than about 13 centimeters per second (cm/s) (25 feet per minute [ft/min]).

In general, this applies to particles larger than 50µm if the particle density is low, down to 10µm if the material density is reasonably high. Particles smaller than this would require excessive horizontal flow distances, which would lead to excessive chamber volumes. The collection efficiency for PM less than or equal to 10µm in aerodynamic diameter (PM_{10}) is typically less than 10 percent. Multiple-tray chambers have lower volume requirements for the collection of particles as small as 15µm (Wark, 1981; Mycock, 1995; EPA, 1998).

Advantages of Settling Chambers (Wark, 1981; Corbitt, 1990; Perry, 1984; Mycock, 1995; and EPA, 1998)

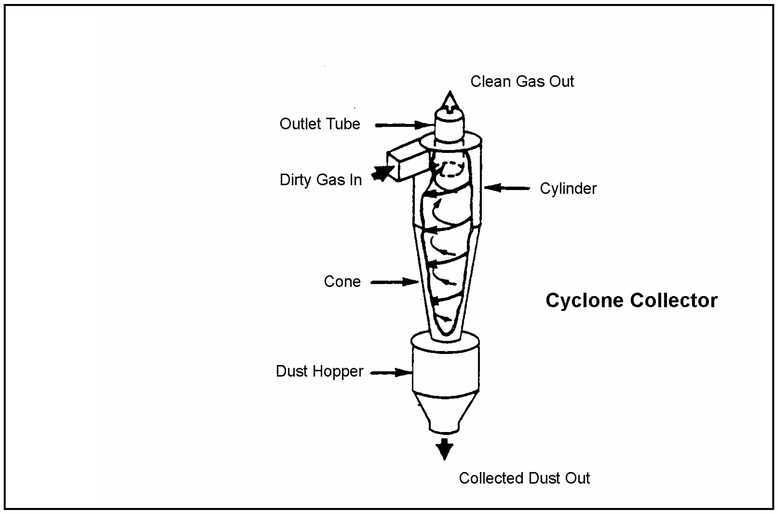
- Low capital cost
- Very low energy cost
- No moving parts
- Few maintenance requirements
- Low operating costs
- Excellent reliability
- Low pressure drop through device
- Device not subject to abrasion due to low gas velocity
- Provide incidental cooling of gas stream
- Dry collection and disposal

Disadvantages of Settling Chambers (Wark, 1981; Mycock, 1995; and EPA, 1998)

- Relatively low PM collection efficiencies
- Unable to handle sticky or tacky materials
- Large physical size
- Trays in multiple-tray settling chamber may warp

Cyclones. This type of air pollution control is also referred to as a "precleaner," because they too are used to reduce the inlet loading of particulate matter (PM) to downstream collection devices by removing larger, abrasive particles. Cyclones are also referred to as cyclone collectors, cyclone separators, centrifugal separators, and inertial separators. In applications where many small cyclones are operating in parallel, the entire system is called a multiple tube cyclone, multicyclone, or multiclone.

Cyclones use inertia to remove particles from the gas stream. Particles in the gas stream are forced toward the cyclone walls by the centrifugal force of the spinning gas and eventually drop out of the bottom of the collector device.



Cyclone Collectors remove particulate matter through use of centrifugal force.

Cyclones use inertia to remove particles from the gas stream. The cyclone imparts centrifugal force on the gas stream, usually within a conical shaped chamber. Cyclones operate by creating a double vortex inside the cyclone body. The incoming gas is forced into a circular motion downward, forcing the particulates to the inner surface of the cyclone walls. At the bottom of the cyclone, the gas turns and then spirals up through the center of the cyclone and exits out of the top outlet (AWMA, 1992). Particles in the gas stream are forced toward the cyclone walls by the centrifugal force of the spinning gas, but are opposed by the fluid drag force of the gas traveling through and out of the cyclone.

For larger particles, inertial momentum overcomes the fluid drag force so that the particles reach the cyclone walls and are collected. For smaller particles, the fluid drag force overwhelms the inertial momentum and causes these particles to leave the cyclone with the exiting gas. Gravity also causes the larger particles that reach the cyclone walls to travel down into a bottom hopper. While they rely on the same separation mechanism as momentum separators, cyclones are more effective because they have a more complex gas flow pattern (AWMA, 1992).

Cyclones are generally classified into four types, depending on how the gas stream is introduced into the device and how the collected dust is discharged. The four types include tangential inlet, axial discharge; axial inlet, axial discharge; tangential inlet, peripheral discharge; and axial inlet, peripheral discharge. The first two types are the most common (AWMA, 1992).

Pressure drop is an important parameter because it relates directly to operating costs and control efficiency. For a given cyclone, higher control efficiencies can be obtained by increasing inlet velocities, but this also increases the pressure drop. In general, 18.3 meters per second (60 feet per second) is considered the best operating velocity. Common ranges of pressure drops for cyclones are 0.5 to 1 kilopascals (kPa) (2 to 4 in. $H_2 O$) for low-efficiency units (high throughput), 1 to 1.5 kPa (4 to 6 in. $H_2 O$) for medium-efficiency units (conventional), and 2 to 2.5 kPa (8 to 10 in. H_2O) for high-efficiency units (AWMA, 1992).

When high-efficiency (which requires small cyclone diameter) and large throughput are both desired, a number of cyclones can be used that contain a large number of tubes with a common gas inlet and outlet in the chamber. The gas enters the tubes through axial inlet vanes, which impart a circular motion (AWMA, 1992). Another high-efficiency unit, the wet cyclonic separator, uses a combination of centrifugal force and water spray to enhance control efficiency.

Cyclones are used to control PM, and primarily PM greater than 10 micrometers (µm) in aerodynamic diameter. However, there are high efficiency cyclones designed to be effective for PM less than or equal to 10µm and less than or equal to 2.5µm in aerodynamic diameter (PM_{10} and $PM_{2.5}$). Although cyclones may be used to collect particles larger than 200µm, gravity settling chambers or simple momentum separators are usually satisfactory and less subject to abrasion (Wark, 1981; Perry, 1984).

The collection efficiency of cyclones varies as a function of particle size and cyclone design. Cyclone efficiency generally increases with (1) particle size and/or density, (2) inlet duct velocity, (3) cyclone body length, (4) number of gas revolutions in the cyclone, (5) ratio of cyclone body diameter to gas exit diameter, (6) dust loading, and (7) smoothness of the cyclone inner wall.

Cyclone efficiency will decrease with increases in (1) gas viscosity, (2) body diameter, (3) gas exit diameter, (4) gas inlet duct area, and (5) gas density. A common factor contributing to decreased control efficiencies in cyclones is leakage of air into the dust outlet (EPA, 1998). Control efficiency ranges for single cyclones are often based on three classifications of cyclone (i.e., conventional, high-efficiency, and high-throughput). The control efficiency range for conventional single cyclones is estimated to be 70 to 90 percent for PM, 30 to 90 percent for PM_{10}, and 0 to 40 percent for $PM_{2.5}$.

Single cyclones have a control efficiency between 80 to 99% percent for PM, 60 to 95% for PM_{10} *, and 20 to 70% for* $PM_{2.5}$.

High efficiency single cyclones are designed to achieve higher control of smaller particles than conventional cyclones. According to Cooper (1994), high efficiency single cyclones can remove 5µm particles at up to 90 percent efficiency, with higher efficiencies achievable for larger particles. The control efficiency ranges for high efficiency single cyclones are 80 to 99 percent for PM, 60 to 95 percent for PM_{10}, and 20 to 70 percent for $PM_{2.5}$. Higher efficiency cyclones come with higher pressure drops, which require higher energy costs to move the waste gas through the cyclone. Cyclone design is generally driven by a specified pressure-drop limitation, rather than by meeting a specified control efficiency (Andriola, 1999; Perry, 1994). According to Vatavuk (1990), high throughput cyclones are only guaranteed to remove particles greater than 20µm, although collection of smaller particles does occur to some extent. The control efficiency ranges for high-throughput cyclones are 80 to 99 percent for PM, 10 to 40 percent for PM_{10} , and 0 to 10 percent for $PM_{2.5}$. Multicyclones are reported to achieve from 80 to 95 percent collection efficiency for 5µm particles (EPA, 1998).

Cyclones are generally not adequate to meet stringent air pollution regulations, but are used extensively after spray drying operations in the food and chemical industries.

Cyclones are designed for many applications. Cyclones themselves are generally not adequate to meet stringent air pollution regulations, but they do serve an important purpose as precleaners for more expensive final control devices such as fabric filters or electrostatic precipitators (ESPs). In addition to use for pollution control work, cyclones are also used in many process applications to recover and recycle food products and process materials such as catalysts (Cooper, 1994).

Cyclones are used extensively after spray drying operations in the food and chemical industries; after crushing, grinding and calcining operations in the mineral and chemical industries; and to collect salable or useful material. In the ferrous and nonferrous metallurgical industries, cyclones are often used as a first stage in the control of PM emissions from sinter plants, roasters, kilns, and furnaces. PM from the fluid-cracking process is removed by cyclones to facilitate catalyst recycling. Fossil fuel and wood-waste fired industrial and commercial fuel combustion units commonly use multiple cyclones (generally upstream of a wet scrubber, ESP, or fabric filter), which collect fine PM (<2.5µm) with greater efficiency than a single cyclone. In some cases, collected fly ash is re-injected into the combustion unit to improve PM control efficiency (AWMA, 1992; Avallone, 1996; STAPPA/ALAPCO, 1996; EPA, 1998).

Advantages of Cyclones (AWMA, 1992; Cooper, 1994; and EPA, 1998)

- Low capital cost
- No moving part
- Few maintenance requirements
- Low operating costs
- Relatively low-pressure drop
- Dry collection and disposal
- Relatively small space requirements

Disadvantages of Cyclones (AWMA, 1992; Cooper, 1994; and EPA, 1998)

- Relatively low PM collection efficiencies
- Unable to handle sticky or tacky materials
- High efficiency units may experience high-pressure drops

Momentum Separators

Momentum separators are an enhancement to settling chambers in that it operates by forcing the exhaust gases to sharply change direction, within a gravity settling chamber, through the use of strategically placed baffles. It is also considered a "precleaner," because it is oftentimes used to reduce the inlet loading of particulate matter (PM) to downstream collection devices by removing larger, abrasive particles. Momentum separators are also referred to as impingement separators, baffle chambers, and knock-out chambers.

Momentum separators operate by forcing waste gas to sharply change direction within a gravity settling chamber through the use of strategically placed baffles. Typically, the gas first flows downward and is then forced by the baffles to suddenly flow upward. Inertial momentum and gravity act in the downward direction on the particles, which causes larger particles to cross the flow lines of the gas and collect in a hopper in the bottom of the chamber (EPA, 1998). The design of momentum separators must provide sufficient volume to allow settling of materials separated from the high-velocity gas stream and materials of construction hard enough to survive high abrasion. As with all mechanical collectors, the design must include methods of sealing dust discharge from hoppers to prevent air leakage. The methods may include use of rotary air locks, flapper valves, or other positive sealing devices. Air leakage through the hopper or shell results in changes in the gas distribution, interferes with dust discharge, and may cause condensation or corrosion. Because of the high velocities used to separate the particles from the gas stream and the impaction of these particles on surfaces that direct the gas flow, the materials of construction must have high abrasion resistance. (EPA,1982)

The collection efficiency of a momentum separator varies as a function of particle size and the momentum separator's design. Momentum separator efficiency generally increases with (1) increased particle size and/or density; (2) increased gas stream velocity; and (3) number of turns, baffles, or other sharp direction changes to gas flow. EPA (1982) presents a fractional collection efficiency curves for two lovered momentum separator controlling fly ash. Fractional collection efficiencies are ≤5 percent for a particle size of 5 μm, 10 to 20 percent for a particle size of 10 μm, and up to 99 percent for particle sizes ≥ 90 μm.

Particulate control devices are designed to capture and store pollutants; however, proper disposal of the pollution is still necessary. Generally, collected particulate matter is disposed of in a landfill while the wastewater generated by scrubbers is sent to treatment facilities. Research is currently being conducted to design better ways to recycle and reuse this collected particulate matter.

NAME ______________________________________ DATE ______________ SCORE_________

CHAPTER 9 CONTROL OF EMISSIONS FROM STATIONARY SOURCES

Multiple Choice

Directions: Read each question and choose the best answer. Write the letter of your answer in the space provided.

1. The following are all principles used to control particulate matter, **except** _______.

a. gravity
b. centrifugal force
c. infrared analysis
d. diffusion
e. electrostatic attraction **1.**________

2. Which of the following control devices might be effectively used to control coarse particulate matter (> 50 microns)?

a. Electrostatic Precipitation Collection Plates
b. Baffle Chambers
c. Baghouse
d. Venturi Scrubber
e. Electrostatic Precipitation Electrodes **2.** ________

3. Settling Chambers use ________ to remove pollutants from gas exhaust.

a. electrostatic precipitation
b. diffusion
c. fabric filters
d. centrifugal force
e. gravity **3.** ________

4. The three T's of combustion are commonly referred to as ________.

a. time , temperature, and type of fuel
b. temperature, type of fuel, and turbulence
c. time, turbulence, and temperature
d. type of fuel, turbulence, and time
e. None of the above **4.** _______

Matching

Directions: *Match each of the following advantages and disadvantages with the proper control technology.*

Control Technology

A. Electrostatic Precipitators
B. Fabric Filters

________ **5.** Is highly efficient (>99%) for collecting all types of dust and high to low flow rates.

________ **6.** Expensive to purchase and maintain and limited by space.

________ **7.** Ability to treat large volumes of gas economically.

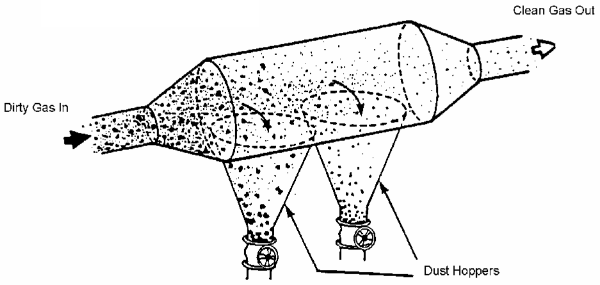
________ **8.** Limited to dry environments.

Control Technology Identification

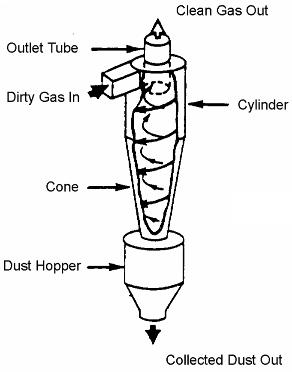
Directions: *Match the control technology with the device that is displayed and answer the questions in the spaces provided.*

A. Electrostatic Precipitator
B. Catalytic Incinerator
C. Contact Condenser
D. Carbon Adsorber
E. Cyclone Collector
F. Elevated Flare System
G. Packed Column Absorber System
H. Fabric Filter
I. Thermal Incinerator
J. Adsorption System
K. Settling Chamber
L. Venturi Scrubber

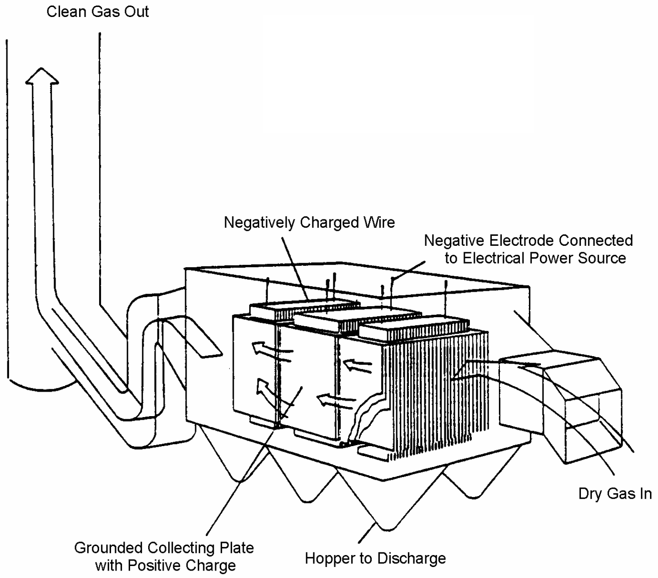
9. _______



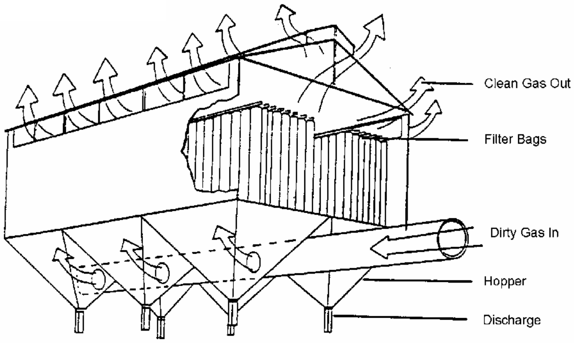
10. _______



11. _______



12. _______



REVIEW ANSWERS

No.	Answer
1.	C
2.	B
3.	E
4.	C
5.	B
6.	A
7.	A
8.	B
9.	K
10.	E
11.	A
12.	H

CHAPTER 10

Control of Stationary Sources (Gaseous Emissions)

Lesson Goal

Demonstrate an understanding of the basic principles, equipment, and methods used to control gaseous emissions generated by stationary sources of air pollution by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Describe the basic principles, equipment, and methods used to control gaseous emissions generated by stationary sources of air pollution.
2. Describe five principles used to control gaseous emissions from stationary sources.
3. Explain how industry determines which type of control technology is appropriate and/or required.
4. Distinguish between methods of controlling emissions that require a control device and those that do not in the control of pollutant emissions.
5. List the types of devices used to control gaseous emissions.
6. Describe the factors that affect collection efficiency.
7. Discuss the influence of emission composition on collection efficiency.

Recommended Reading: Godish, Thad, “Control of Emissions from Stationary Sources,” *Air* Quality, 3rd Edition, New York: Lewis, 1997, pp. 309-340.

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Control of Stationary Sources, Gaseous Emissions

Stationary sources such as power plants, chemical production facilities, oil refineries, manufacturing plants, printers, dry cleaners, and even residential wood stoves produce a significant amount of the criteria and hazardous air pollutants (HAPs), that are emitted in the atmosphere each day. The emitted pollutants can be in the form of particulate matter (PM), PM as listed HAPs, or gases such as: sulfur oxides, nitrogen oxides volatile organic compounds, or other HAPs listed gases.

Most of the air pollution produced by stationary sources results from the incomplete combustion of fuel or industrial processing.

Gaseous Emissions

The preferred method for controlling gaseous pollutants is with add-on control devices used to destroy or recover the pollutant. The control techniques used by add-on equipment include combustion, adsorption, absorption, and condensation. Combustion devices currently in use include thermal or catalytic incinerators, flares, boilers, and process heaters. The following section provides a brief description of gaseous control devices and the various techniques used to eliminate NOx, CO, or other harmful gases.

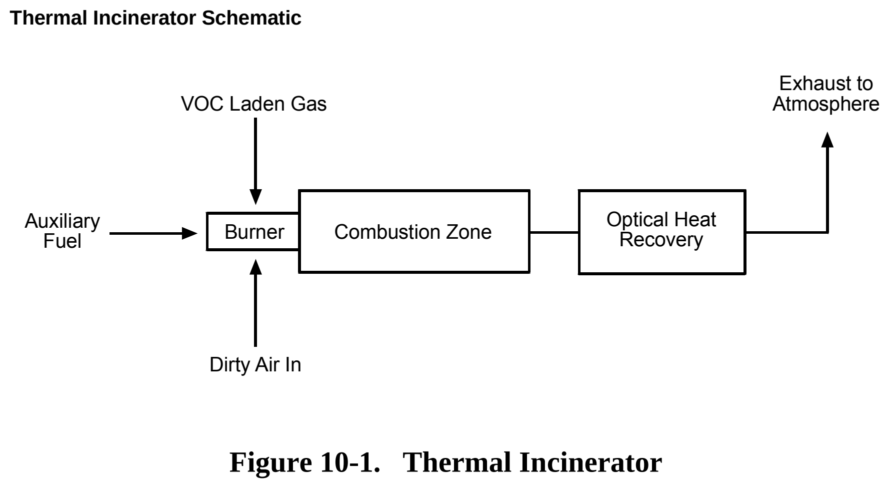


Figure 10-1. Thermal Incinerator

Control Equipment for Gaseous Emissions:

- *Thermal Incinerators*
- *Catalytic Incubators*
- *Flares*
- *Boilers and Process Heaters*
- *Carbon Adsorbers*
- *Absorbers*
- *Condensers*

Thermal Incinerators dispose of gaseous pollutants by high temperature combustion.

Thermal Incinerators. Thermal incinerators are commonly used to destroy volatile organic compounds (VOCs). In general, incineration involves the destruction of liquid, solid, or gaseous waste by a controlled burn at high temperatures. Incinerators are one of the most positive and proven methods for destroying VOC, with efficiencies up to 99.9% possible. Thermal incinerators are often the best choice when high efficiencies are needed and the waste gas is above 20% of the LEL.

One advantage of thermal incineration is that the energy and heat produced by the process can be recovered and used to power other processes in the facility. Incineration, or thermal oxidation is the process of oxidizing combustible materials by raising the temperature of the material above its auto-ignition point in the presence of oxygen, and maintaining it at high temperature for sufficient time to complete combustion to carbon dioxide and water. Time, temperature, turbulence (for mixing), and the availability of oxygen all affect the rate and efficiency of the combustion process. These factors provide the basic design parameters for VOC oxidation systems (ICAC, 1999).

A straight thermal incinerator is comprised of a combustion chamber and does not include any heat recovery of exhaust air by a heat exchanger (this type of incinerator is referred to as a recuperative incinerator). The heart of the thermal incinerator is a nozzle-stabilized flame maintained by a combination of auxiliary fuel, waste gas compounds, and supplemental air added when necessary. On passing through the flame, the waste gas is heated from its preheated inlet temperature to its ignition temperature. The ignition temperature varies for different compounds and is usually determined empirically. An ignition temperature is the temperature at which the combustion reaction rate exceeds the rate of heat losses, thereby raising the temperature of the gases to some higher value.

Thus, any organic/air mixture will ignite if its temperature is raised to a sufficiently high level (EPA, 1996a). The required level of VOC control of the waste gas that must be achieved within the time that it spends in the thermal combustion chamber dictates the reactor temperature. The shorter the residence time, the higher the reactor temperature must be. The nominal residence time of the reacting waste gas in the combustion chamber is defined as the combustion chamber volume divided by the volumetric flow rate of the gas. Most thermal units are designed to provide no more than 1 second of residence time to the waste gas with typical temperatures of 650° to 1100 °C (1200° to 2000 °F). Once the unit is designed and built, the residence time is not easily changed, so that the required reaction temperature becomes a function of the particular gaseous species and the desired level of control (EPA, 1996).

Studies based on actual field test data, show that commercial incinerators should generally be run at 870°C (1600°F) with a nominal residence time of 0.75 seconds to ensure 98% destruction of non-halogenated organics (EPA, 1992).

VOC destruction efficiency depends on design criteria (i.e., chamber temperature, residence time, inlet VOC concentration, compound type, and degree of mixing) (EPA, 1992). Typical thermal incinerator design efficiencies range from 98 to 99.99% and above, depending on system requirements and characteristics of the contaminated stream (EPA, 1992; EPA, 1996). Specific design conditions needed to meet >98% control or a 20 parts per million by volume (ppmv). The recommended conditions at exit are 870°C (1600°F) combustion temperature, 0.75-second residence time, and proper mixing. For halogenated VOC streams, the recommended conditions are 1100°C (2000 °F) combustion temperature, 1.0-second residence time, and use of an acid gas scrubber on the outlet is recommended (EPA, 1992). For vent streams with VOC concentration below approximately 2000 ppmv, reaction rates decrease, maximum VOC destruction efficiency decreases, and an incinerator outlet VOC concentration of 20 ppmv or lower may be achieved (EPA, 1992).

Controlled emissions and/or efficiency test data for PM in incinerators are not generally available in the literature. However, emission factors for PM in phthalic anhydride processes with incinerators are available. The PM control efficiencies for these processes were found to vary from 79 to 96% (EPA, 1998). In EPA's 1990 National Inventory, incinerators used as control devices for PM were reported as achieving 25 to 99% control efficiency of particulate matter 10 microns or less in aerodynamic diameter (PM_{10}) at point source facilities (EPA, 1998). Table 9-3 presents a breakdown of the PM_{10} control efficiency ranges by industry for recuperative incinerators (EPA, 1996). The VOC control efficiency reported for these devices ranged from 0 to 99.9%.

Thermal incinerators have a PM control efficiency that varies between 79 and 96%, while VOC control efficiencies can range as high as 99.9%..

Table 10-1. Thermal Incinerator PM_{10} Destruction Efficiencies by Industry. (EPA, 1996)

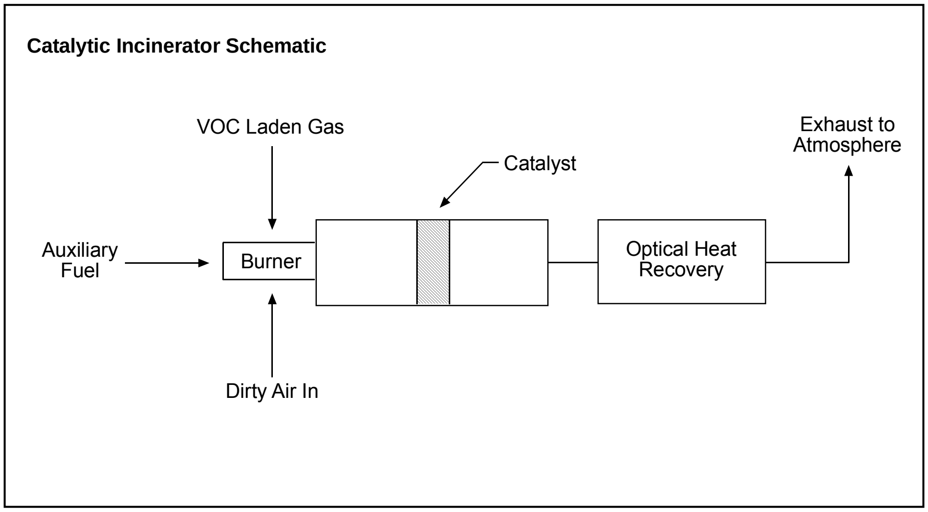
Industry/Types of Sources	PM_{10} Control Efficiency (%)
Petroleum and Coal Products Asphalt roofing processes (blowing, felt, saturation); mineral calcining; petroleum refinery processes (asphalt blowing, catalytic cracking, coke calcining, sludge converter); sulfur mfg.	25 – 99.9%
Chemical and Allied Products Carbon black manufacturing (mfg); charcoal mfg; liquid waste disposal; miscellaneous chemical mfg processes; pesticide mfg; phthalic anhydride mfg (xylene oxidation); plastics/synthetic organic fiber mfg; solid waste incineration (industrial)	50 – 99.9%
Primary Metals Industries By-product coke processes (coal unloading, oven charging and pushing, quenching); gray iron cupola and other miscellaneous processes; secondary aluminum processes (burning/drying, smelting furnace); secondary copper processes (scrap drying, scrap cupola and miscellaneous processes); steel foundry miscellaneous processes; surface coating oven	70 – 99.9%

Electronic and Other Electric Equipment Chemical mfg miscellaneous processes; electrical equipment bake furnace; fixed roof tank; mineral production miscellaneous processes; secondary aluminum roll/draw extruding; solid waste incineration (industrial)	70 – 99.9%
Electric, Gas, and Sanitary Services Internal combustion engines; solid waste incineration (industrial, commercial/ institutional)	90 – 98%
Stone, Clay, and Glass Products Barium processing kiln; coal cleaning thermal dryer; fabricated plastics machinery; wool mfg.	50 – 95%

Thermal incinerators are also not generally cost-effective for low-concentration, high-flow organic vapor streams (EPA, 1995). Thermal incinerators are not usually as economical, on an annualized basis, as recuperative or regenerative incinerators because they do not recover waste heat energy from the exhaust gases. This heat can be used to preheat incoming air, thus reducing the amount of supplemental fuel required. If there is additional heat energy available, it can be used for other process heating needs.

Catalytic Incinerators. Catalytic incinerators operate very similarly to thermal/recuperative incinerators, with the primary difference being that the gas, after passing through the flame area, passes through a catalyst bed. The catalyst has the effect of increasing the oxidation reaction rate, enabling conversion at lower reaction temperatures than in thermal incinerator units. Therefore, catalysts also allow for smaller incinerator size. Catalysts typically used for VOC incineration include platinum and palladium. Other formulations include metal oxides, which are used for gas streams containing chlorinated compounds (EPA, 1998).

Catalytic incinerators operate very similar to thermal incinerators. The primary difference is that the gas, after passing through the flame area, passes through a catalyst bed.



Catalytic Incinerators use a catalyst rather than heat to hasten disposal through the combustion process. Platinum and palladium are the most efficient catalysts.

In a catalytic incinerator, the gas stream is introduced into a mixing chamber where it is also heated. The waste gas usually passes through a recuperative heat exchanger where it is preheated by post combustion gas. The heated gas then passes through the catalyst bed. Oxygen and VOCs migrate to the catalyst surface by gas diffusion and are adsorbed onto the catalyst active sites on the surface of the catalyst where oxidation then occurs. The oxidation reaction products are then desorbed from the active sites by the gas and transferred by diffusion back into the gas stream (EPA, 1998).

Particulate matter can rapidly coat the catalyst so that the catalyst active sites are prevented from aiding in the oxidation of pollutants in the gas stream. This effect of PM on the catalyst is called blinding, and will deactivate the catalyst over time. Because essentially all the active surface of the catalyst is contained in relatively small pores, the PM need not be large to blind the catalyst. No general guidelines exist as to the PM concentration and size that can be tolerated by catalysts because the pore size and volume of catalysts vary widely. This information is likely to be available from the catalyst manufacturers (EPA, 1996).

The method of contacting the VOC-laden stream with the catalyst serves to distinguish catalytic incineration systems. Both fixed-bed and fluid-bed systems are used. Fixed-bed catalytic incinerators may use a monolith catalyst or a packed-bed catalyst (EPA, 1996).

The most widespread method of contacting the VOC-laden stream with the catalyst is the catalyst monolith. In this scheme the catalyst is a porous solid block containing parallel, nonintersecting channels aligned in the direction of the gas flow. Monoliths offer the advantages of minimal attrition due to thermal expansion/contraction during startup/shutdown and low overall pressure drop.

A second contacting scheme is a simple packed-bed in which catalyst particles are supported either in a tube or in shallow trays through which the gases pass. This scheme is not in widespread use due to its inherently high pressure drop, compared to a monolith, and because the catalyst particles break due to thermal expansion. However, the tray type arrangement of a packed-bed scheme, where the catalyst is pelletized, is used by several industries (i.e., heat-set web-offset printing). A pelletized catalyst is advantageous where large amounts of such contaminants as phosphorous or silicon compounds are present.

Fluid-bed catalytic incinerators have the advantage of very high mass transfer rates, although the overall pressure drop is somewhat higher than for a monolith. An additional advantage of fluid-beds is a high bedside heat transfer as compared to a normal gas heat transfer coefficient.

This higher heat transfer rate to heat transfer tubes immersed in the bed allows higher heat release rates per unit volume of gas processed and, therefore, may allow waste gas with higher heating values to be processed without exceeding maximum permissible temperatures in the catalyst bed. In these reactors, the gas phase temperature rise from gas inlet to gas outlet is low, depending on the extent of heat transfer through imbedded heat transfer surfaces. The catalyst temperatures depend on the rate of reaction occurring at the catalyst surface and the rate of heat exchange between the catalyst and imbedded heat transfer surfaces.

As a general rule, fluid-bed systems are more tolerant of PM in the gas stream than either fixed-bed or monolithic catalysts. This is due to the constant abrasion of the fluidized catalyst pellets, which helps remove PM from the exterior of the catalysts in a continuous manner. One disadvantage of a fluid-bed is the gradual loss of catalyst by attrition. However, in recent years scientists have developed attrition-resistant catalysts to overcome this problem.

As a general rule, fluid-bed systems are more tolerant of PM in the gas stream than either fixed-bed or monolithic catalysts. However, a disadvantage of the fluidized bed incinerator is that the catalyst is gradually lost by attrition.

Catalytic incinerators can be used to reduce emissions from a variety of stationary sources. Solvent evaporation processes associated with surface coating and printing operations are a major source of VOC emissions, and catalytic incineration is widely used by many industries in this category. Catalytic incinerators are also used to control emissions from the following sources (EPA, 1992):

- Varnish cookers
- Foundry core ovens
- Filter paper processing ovens
- Plywood veneer dryers
- Gasoline bulk loading stations
- Process vents in the synthetic organic chemical manufacturing industry (SOCMI)
- Rubber products and polymer manufacturing
- Polyethylene, polystyrene, and polyester resin manufacturing

Catalytic oxidation is most suited to systems with lower exhaust volumes, when there is little variation in the type and concentration of VOC, and where catalyst poisons or other fouling contaminants such as silicone, sulfur, heavy hydrocarbons and particulates are not present.

VOC destruction efficiency is dependent on VOC composition and concentration, operating temperature, oxygen concentration, catalyst characteristics, and space velocity. Space velocity is commonly defined as the volumetric flow of gas entering the catalyst bed chamber divided by the volume of the catalyst bed. The relationship between space velocity and VOC destruction efficiency is strongly influenced by catalyst operating temperature.

Catalytic incinerators have PM control efficiencies between 25 and 99%, while VOC reductions range as high as 99.9%.

As space velocity increases, VOC destruction efficiency decreases, and as temperature increases, VOC destruction efficiency increases. As an example, a catalytic unit operating at about 450°C (840°F) with a catalyst bed volume of 0.014 to 0.057 cubic meter (m^3) (0.5 to 2 cubic feet (ft^3) per 0.47 standard cubic meters per second (sm ^{3} /sec) (1,000 standard cubic feet per minute (scfm) of offgas passing through the device can achieve 95 percent VOC destruction efficiency (EPA, 1992). Higher destruction efficiencies of 98 to 99 percent are achievable, but require larger catalyst volumes and/or higher temperatures, and are usually designed on a site-specific basis (EPA, 1991). In EPA's 1990 National Inventory, incinerators as a group, including catalytic incinerators, were reportedly used as control devices for PM and were apparently achieving a 25 to 99 percent control efficiency of PM_{10} at point source facilities (EPA, 1998).

Table 10-2 presents a breakdown of the PM_{10} control efficiency ranges by industry where catalytic incinerators have been reported (EPA, 1996b). The VOC control efficiency reported for these devices ranged from 0 to 99.9%; however, it is assumed that reports of higher efficiencies (greater than 99%) are attributable to thermal incinerators. These ranges of control efficiencies are large because they include facilities that do not have VOC emissions and control only PM, as well as facilities that have low PM emissions and are primarily concerned with controlling VOC (EPA, 1998).

Advantages of Catalytic Incinerators (AWMA, 1992; Cooper and Alley, 1994)

- Lower fuel requirements
- Lower operating temperatures
- Little or no insulation requirements
- Reduced fire hazards
- Reduced flashback problems
- Less volume/size required

Disadvantages of Catalytic Incinerators (AWMA, 1992)

- High initial cost
- Catalyst poisoning is possible
- Particulate often must first be removed
- Disposal problems for spent catalyst

Catalytic incinerators offer many advantages for the appropriate application. However, selection of a catalytic incinerator should be considered carefully, as the sensitivity of catalytic incinerators to VOC inlet stream flow conditions and catalyst deactivation limit their applicability for many industrial processes (EPA, 1992).

Table 10-2. PM_{10} Destruction Efficiencies for Catalytic Incinerators and Catalytic Incinerators with Heat Exchanger by Industry. (EPA, 1996)

Industry/Types of Sources	PM_{10} Control Efficiency (%)
Petroleum and Coal Products Asphalt roofing processes (blowing, felt saturation); mineral calcining; petroleum refinery processes (asphalt blowing, catalytic cracking, coke calcining, sludge converter); sulfur manufacturing	25 – 99.9%
Chemical and Allied Products Carbon black manufacturing (mfg); charcoal mfg; liquid waste disposal; miscellaneous chemical mfg processes; pesticide mfg; phthalic anhydride mfg (xylene oxidation); plastics/synthetic organic fiber mfg; solid waste incineration (industrial)	50 – 99.9%
Primary Metals Industries By-product coke processes (coal unloading, oven charging and pushing, quenching); gray iron cupola and other miscellaneous processes; secondary aluminum processes (burning/drying, smelting furnace); secondary copper processes (scrap drying, scrap cupola, and miscellaneous processes); steel foundry miscellaneous processes; surface coating oven	70 – 99.9%
Electronic and Other Electric Equipment Chemical mfg miscellaneous processes; electrical equipment bake furnace; fixed roof tank; mineral production miscellaneous processes; secondary aluminum roll/draw extruding; solid waste incineration	70 – 99.9%
Electric, Gas, and Sanitary Services Internal combustion engines; solid waste incineration (industrial, commercial/ institutional)	90 – 98%
Stone, Clay, and Glass Products Barium processing kiln; coal cleaning thermal dryer; fabricated plastics machinery; wool fiberglass mfg.	50 – 95%
Mining Asphalt concrete rotary dryer; organic chemical air oxidation units, sulfur production	70 – 99.6%

Paper and Allied Products Boiler	95%
Printing and Publishing Surface coating dryer; fugitives	95%

Flares. Flaring is a VOC combustion control process in which the VOCs are piped to a remote, usually elevated, location and burned in an open flame in the open air using a specially designed burner tip, auxiliary fuel, and steam or air to promote mixing for nearly complete (>98%) VOC destruction. Completeness of combustion in a flare is governed by flame temperature, residence time in the combustion zone, turbulent mixing of the gas stream components to complete the oxidation reaction, and available oxygen for free radical formation. Combustion is complete if all VOCs are converted to carbon dioxide and water. Incomplete combustion results in some of the VOCs being unaltered or converted to other organic compounds such as aldehydes or acids.

Flares are generally categorized in two ways: (1) by the height of the flare tip (i.e., ground or elevated), and (2) by the method of enhancing mixing at the flare tip (i.e., steam-assisted, air-assisted, pressure-assisted, or non-assisted). Elevating the flare can prevent potentially dangerous conditions at ground level where the open flame (i.e., an ignition source) is located near a process unit. Elevating the flare also allows the products of combustion to be dispersed above working areas to reduce the effects of noise, heat, smoke, and objectionable odors. In most flares, combustion occurs by means of a diffusion flame. A diffusion flame is one in which air diffuses across the boundary of the fuel/combustion product stream toward the center of the fuel flow, forming the envelope of a combustible gas mixture around a core of fuel gas.

Flares are typically used as a last resort to dispose of gases that are of little recyclable value or are not easily combustible.

Gases flared from refineries, petroleum production, and the chemical industry are composed largely of low molecular weight VOC and have high heating values.

This mixture, on ignition, establishes a stable flame zone around the gas core above the burner tip. This inner gas core is heated by diffusion of hot combustion products from the flame zone. Cracking can occur with the formation of small, hot particles of carbon that give the flame its characteristic luminosity. If there is oxygen deficiency and if the carbon particles are cooled to below their ignition temperature, smoking occurs. In large diffusion flames, combustion product vortices can form around burning portions of the gas and shut off the oxygen supply. This localized instability causes flame flickering, which can be accompanied by soot formation.

Steam-assisted burn vented gas in a diffusion flame. They reportedly account for the majority of the flares installed and are the predominant flare type found in refineries and chemical plants.

As in all combustion processes, an adequate air supply and good mixing are required to complete combustion and minimize smoke. The various flare designs differ primarily by their ability to mix air with the combustibles. Steam-assisted flares are single burner tips, elevated above ground level for safety reasons that burn the vented gas in a diffusion flame. They reportedly account for the majority of the flares installed and are the predominant flare type found in refineries and chemical plants. To ensure an adequate air supply and good mixing, this type of flare system injects steam into the combustion zone to promote turbulence for mixing and to induce air into the flame.

Some flares use forced air to provide the combustion air and the mixing required for smokeless operation. These flares are built with a spider-shaped burner (with many small gas orifices) located inside, but near the top of a steel cylinder 0.6 meters (24 inches) or more in diameter.

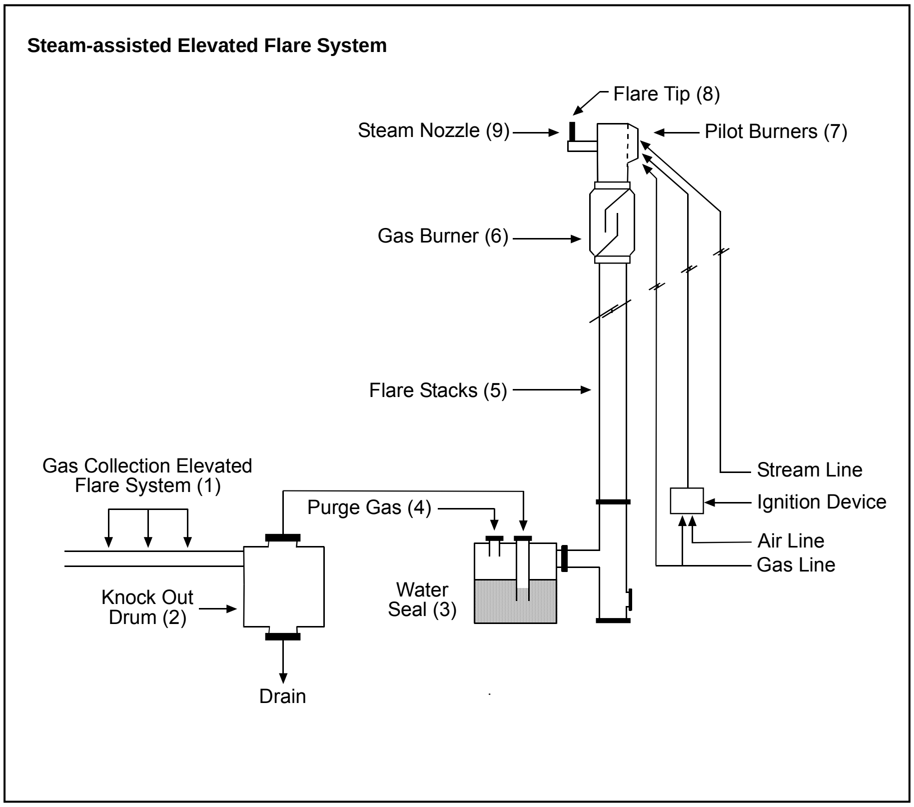


Figure 10-3. Flare System

A fan in the bottom of the cylinder provides combustion air. Varying the fan speed can vary the amount of combustion air. The principal advantage of air-assisted flares is that they can be used where steam is not available. Although air assistance is not usually necessary on large flares (because it is generally not economical when the gas volume is large) the number of large, air-assisted flares being built is increasing.

The non-assisted flare consists of a flare tip without any auxiliary provision for enhancing the mixing of air into its flame. Its use is limited to gas streams that have low heat content and a low carbon/hydrogen ratio that burn readily without producing smoke. These streams require less air for complete combustion, have lower combustion temperatures that minimize cracking reactions, and are more resistant to cracking. Pressure-assisted flares use the vent stream pressure to promote mixing at the burner tip.

Several vendors now market proprietary, high pressure drop burner tip designs. If sufficient vent stream pressure is available, these flares can be applied to streams previously requiring steam or air assist for smokeless operation. Pressure-assisted flares generally (but not necessarily) have the burner arrangement at ground level, and consequently must be located in a remote area of the plant where there is plenty of space available. They have multiple burner heads that are staged to operate based on the quantity of gas being released. The size, design, number, and group arrangement of the burner heads typically depend on the vent gas characteristics.

An enclosed flare's burner heads are inside a shell that is internally insulated. The shell reduces noise, luminosity, and heat radiation and provides wind protection. Enclosed, or ground-based flares are generally used instead of elevated flares for aesthetic or safety reasons. A high nozzle pressure drop is usually adequate to provide the mixing necessary for smokeless operation where air or steam assistance is not required. In this context, enclosed flares can be considered a special class of pressure-assisted or non-assisted flares. The height must be adequate for creating enough draft to supply sufficient air for smokeless combustion and for dispersion of the thermal plume. These flares are always at ground level.

Enclosed flares generally have less capacity than open flares and are used to combust continuous, constant flow vent streams; although reliable and efficient operation can be attained over a wide range of design capacity. Stable combustion can be obtained with lower heat content vent gases than is possible with open flare designs (1.9 to 2.2 MJ/sm 3 [50 to 60 Btu/scf]), probably due to their isolation from wind effects. Enclosed flares are typically used at landfills to destroy landfill gas (EPA, 1995).

Flares can be used to control almost any VOC stream, and can typically handle large fluctuations in VOC concentration, flow rate, heating value, and inert species content. Flaring is appropriate for continuous, batch, and variable flow vent stream applications, but the primary use is that of a safety device used to control a large volume of pollutant resulting from upset conditions. Flares find their primary application in the petroleum and petrochemical industries.

The majority of chemical plants and refineries have existing flare systems designed to relieve emergency process upsets that require release of large volumes of gas. These large diameter flares are designed to handle emergency releases, but can also be used to control vent streams from various process operations. Gases flared from refineries, petroleum production, and chemical industries are composed largely of low molecular weight VOC and have high heating values. Flares used to control waste gases from blast furnaces consist of inert species and carbon monoxide with a low heating value. Gases flared from coke ovens are intermediate in composition to the other two groups and have a moderate heating value (EPA, 1995; EPA, 1992).

Depending on the type of flare configuration (i.e., elevated or ground flares) and the source of the waste stream, the capacity of flares to treat waste gases can vary up to about 50,000 kilograms per hour (kg/hr) (100,000 pounds per hour (lb/hr) of hydrocarbon gases for ground flares and about 1 million kg/hr (2 million lb/hr) or more for elevated flares (EPA, 1991). Flares are not subject to the safety concern of incinerators regarding having a high concentration of organics in the waste gas. This is because flaring is an open combustion process and does not have an enclosed combustion chamber that can create an explosive environment. Incinerators, however, have an enclosed combustion chamber, which requires that the concentration of the waste gas be substantially below the lower flammable level (lower explosive limit, or LEL) of the specific compound being controlled to avoid the potential for explosion, as a rule, a safety factor of four (i.e., 25% of the LEL) is used.

The waste gas stream must have a heating value of greater than 11 MJ/scm (300 Btu/scf). If the waste gas does not meet this minimum, auxiliary fuel must be introduced in sufficient quantity to make up the difference (EPA, 1995).

Liquids that may be in the vent stream gas or that may condense out in the collection header and transfer lines are removed by a knockout drum. The knockout or disentrainment drum is typically either a horizontal or vertical vessel located at or close to the base of the flare, or in a vertical vessel located inside the base of the flare stack. Liquid in the vent stream can extinguish the flame or cause irregular combustion and smoking. In addition, flaring liquids can generate a spray of burning chemicals that could reach ground level and create a safety hazard (EPA, 1995).

Advantages of Flares (EPA, 1992; EPA, 1991)

- Economical way to dispose of gas
- Does not require auxiliary fuel to support combustion
- Used to control intermittent or fluctuating waste streams

Disadvantages of Flares (EPA, 1995)

- Produces undesirable noise, smoke, heat radiation, and light
- Source of SOx , NOx , and CO
- Cannot treat waste streams with halogenated compounds
- Released heat from combustion is lost

When boilers or process heaters are used as pollution control devices, they frequently achieve removal efficiencies of 98% or more.

Boilers and Process Heaters. Boilers and process heaters are commonly used by production facilities to generate heat and power. Although their primary purpose is to contribute to plant operations, they can also be used quite effectively as a pollution control device by recycling the pollutant for fuel. However, the only pollutants that can be used for fuel are those that do not affect the performance of the burner unit. For example, an exhaust stream can be used as supplementary fuel, but only if its fuel value is sufficient to maintain the combustion process. All volatile organic compounds (VOCs) have different heating values. If the pollutant stream is large and the heating value is high, the exhaust can be a primary source of fuel for the plant. However, gas streams with low heating values can only be used with a boiler or heater that is small enough to accommodate the reduced fuel value.

When boilers or process heaters are used as pollution control devices, they frequently achieve removal efficiencies of 98 percent or more. An advantage of using these devices for pollution control is that there is little additional capital cost involved since they are already required for operating the plant. In addition, exhaust streams reduce fuel costs by recycling and reusing products from the refining process.

Adsorbers. Adsorbers have been used primarily to control the emission of VOCs. The control of VOC emissions typically reduces the concentrations from between 400 and 2,000 parts per million (ppm) to under 50 ppm. Adsorption technology can now extend the range of VOC concentrations from 20 ppm to one-fourth of the Lower Explosive Limit (LEL). At the lower end of this range, such small concentrations may be difficult or uneconomical to control by another technology or even by all adsorbents. Incinerators, membrane separators, and condensers may be economically feasible when used in place of absorbers at the upper end of the range.

Adsorbers may be either regenerative or nonregenerative; however, nonregenerative adsorbers are not typically used due to problems of solid waste disposal

In addition to emission control, the adsorber makes recovery of the VOC possible. Recovery of a reusable or marketable VOC can significantly offset the cost of emission control. Adsorbers can also increase the concentration of VOC to allow either destruction by incineration, or recovery by either membrane or condenser to be economically feasible. In the adsorption process, the pollutant is adsorbed on the surface (mostly the internal surface) of a granule, bead, or crystal of adsorbent material. It is not absorbed by a chemical reaction. This is an important difference. The adsorbed material is held physically, rather loosely, and can be released or desorbed rather easily by either heat or vacuum.

By contrast, an absorber reacts chemically with the substance being absorbed, and thus holds the absorbed substance more strongly, requiring more energy to release the absorbed substance. Unfortunately, one of the adsorbents is called “absorbent carbon.” This persisting misnomer came from the time before adsorption became understood in the 1920s. A better term is “activated carbon.” Carbon is activated by the pyrolysis of coal, wood, bark, coconut husks, etc. to remove all the volatile material as a gas or vapor, leaving only the carbon. This carbon might then be partially oxidized to enlarge its pores.

Carbon adsorption systems can be either regenerative or non-regenerative. A regenerative system contains more than one carbon bed. As one bed is used to actively remove pollutants, another bed is cleaned and prepared for future use. Steam can be used to purge the captured pollutant from the bed, and the pollutant is either recycled or destroyed. By “regenerating” the carbon, the same activated carbon material can be used again and again.

Regenerative systems are best used when the concentration of the pollutant in the gas stream is relatively high. Carbon needs to be replaced every six months to five years, or when there is a bed fire. The frequency depends on the type of carbon, the frequency of regeneration, and the temperature at which it operates. On the other hand, non-regenerative systems usually have thinner beds of activated carbon and are discarded when they become saturated with the pollutant. Because the carbon coated pollutant residue creates a solid waste problem, non-regenerative carbon adsorbers are generally used only when the pollutant concentration is extremely low.

Regenerative systems are best used when the concentration of the pollutant in the gas stream is relatively high.

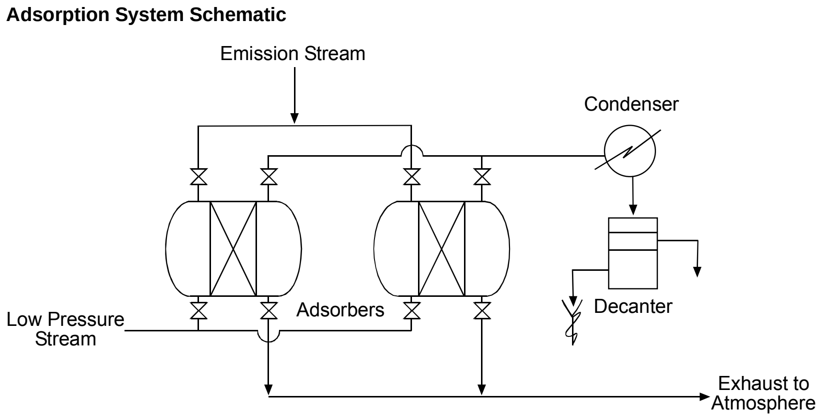


Figure 10-4. Carbon Adsorber

Each adsorbent has an adsorption capacity, which is referred to as the “adsorption isotherm.” Historically, with carbon, the isotherm was used to measure the pounds of pollutant per pound of adsorbent that could be adsorbed at a given temperature. However, the adsorption isotherm is also a function of pollutant concentration as measured by the partial pressure of the vapor, and it is also a function of the total ambient pressure around the adsorbent. The number of molecules that can be stored in the “well” is pressure dependent, with closer spacing of adsorbed molecules being associated with higher pressure. The adsorption isotherm is still defined as the pounds of material that can be adsorbed per pound of adsorbent.

There are three methods of regeneration: thermal swing regeneration, vacuum regeneration, and pressure swing adsorption. Thermal regeneration systems use the temperature isotherm; vacuum regeneration systems use the total and partial pressure isotherm; and pressure swing regeneration systems use the total ambient pressure isotherm. The "isotherm" is actually a function of all of these variables. Thus, the "isotherm" is actually a complex function that forms at least a three-dimensional surface, rather than being either a constant or a two-dimensional plot. The isotherm can either be a linear function or a highly non-linear function depending on the adsorbent, the pressure, and the material being adsorbed.

The adsorption isotherm is also a function of the amount of adsorption area that molecules of the VOC can reach. Pores on the surface allow entry to the interior area of each of these adsorbents. The interior is where most of the adsorption area exists. Carbon has pores leading to smaller pores, which lead to even smaller pores. This apparently continues ad infinitum in carbon, and much of the internal surface area is in these micro-pores.

The affinity of the adsorbent for some types of substances can be much greater than the affinity for others. As a result, when there is a stronger affinity for some of the molecules, the molecules having lesser affinity either get held with a smaller adsorption capacity or get released in favor of the molecules for which the affinity is greater. Carbon, which is neither fully hydrophobic nor hydrophilic, retains some adsorption area with an affinity for both polar and non-polar molecules. Humidity has a noticeable effect on carbon because of this. One research paper has even reported that desorbing of VOC from carbon occurs as steam condenses and the water displaces the VOC.

The Mass Transfer Zone (MTZ) exists in all adsorbents. In the MTZ, the concentration of VOC in air goes from 100% of the inlet vapor concentration to the lowest available vapor pressure in equilibrium with the desorbed adsorbent.

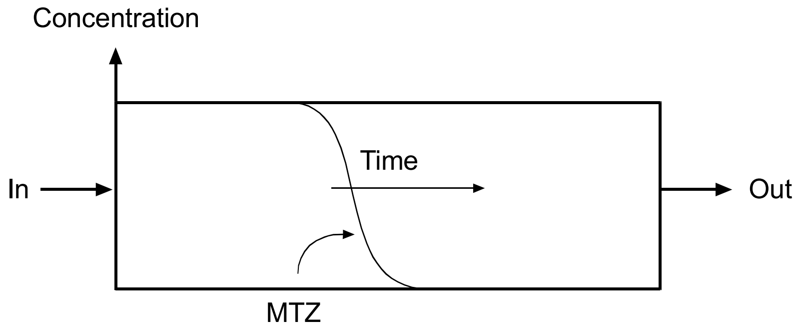


Figure 10-5. Mass Transfer Zone (MTZ)

The Mass Transfer Zone (MTZ), see Figure 10-5, exists in all adsorbents. In the MTZ, the concentration of VOC in air goes from 100% of the inlet vapor concentration to the lowest available vapor pressure in equilibrium with the desorbed adsorbent. The depth of the bed is the dimension of the adsorbent in the direction of airflow, and the MTZ is usually much shorter than the depth of the bed. The MTZ moves through the bed and as the bed reaches its capacity the absorption isotherm becomes filled. Upstream of the MTZ, the bed has reached its capacity; while downstream the bed remains essentially desorbed. Breakthrough occurs when the MTZ reaches the downstream end of the adsorption bed and is observed as a rise in the VOC vapor concentration, leaving the bed, which may occur at different times for different VOC.

Adsorbents of all types share a characteristic with columns used in gas chromatography, for these too use adsorption. The adsorbed material will desorb spontaneously and migrate downstream with the gas flow in each system. This is caused by the pressure gradient, which is intentionally very low when adsorbers are used as an emission control technology, and rather high in the gas chromatography adsorption column. This migration of pollutants is generally slow enough that it may be neglected when emissions are being controlled. However, this property defines an absolute maximum time for adsorption before regeneration of the bed. Breakthrough is actually a gradual process because the equilibrium between the vapor pressure and the adsorbent is continuously varying. Thus, breakthrough can be defined as any noticeable rise in the effluent concentration.

The MTZ will also migrate to breakthrough independent of the VOC loading. An input spike of VOC, along with the migration of the MTZ, will allow the spread of the VOC and reduce the concentration that will be desorbed at breakthrough. An example of how an adsorber might properly use the migration characteristic of the MTZ is in air flow from a hood in a plant that handles mercaptan. Natural gas is odorless, so mercaptan is added to natural gas to provide an olfactory (odor) indication of a leak.

If the mercaptan spill gave emissions in concentrations more than one part per billion, people would smell it, and be alarmed because they would think that there was a leak of natural gas. Therefore, hoods where mercaptan is handled are equipped with a suitably sized adsorber. This adsorber captures any vapors from spills and, when the MTZ migrates to breakthrough, the mercaptan is released at a lower concentration. This is because the mercaptan was not a continuous emission. Rather the adsorber did not reach its capacity, so therefore breakthrough occurred at a lower concentration, which was below the threshold of smell. For this reason, desorbing or regeneration is not necessary unless the spills are too frequent.

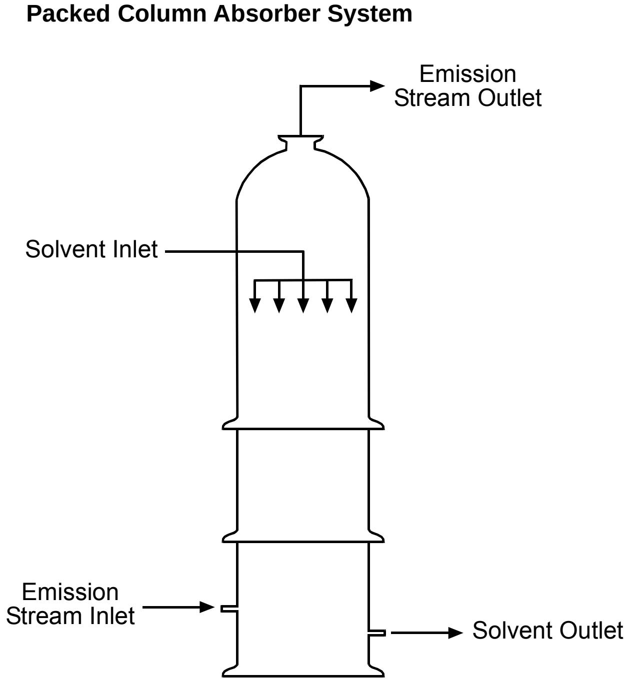


Figure 10-6. Packed Column Absorber

The “conditioning cycles” are the number of cycles (often about five) that are required to achieve a stable amount of adsorption and regeneration. Carbon, after undergoing the conditioning cycles, is capable of adsorbing about 50% of the amount that was adsorbed by the virgin material. Zeolite is capable of adsorbing about 90% of the amount adsorbed by the virgin material.

Polymers can vary over the range of 50 to 90 percent. This “conditioned isotherm” also defines the “working capacity” of the adsorbent. The fact that carbon and some polymers will typically desorb only 50 percent as much as the virgin material is thought to be caused by the continued recapture of molecules (i.e., depressed vapor pressure) in the micro-pores. VOC can be removed from these micropores only by pyrolysis, which would destroy the VOC, and either destroy the polymer or alter the properties of the carbon.

The "working capacity" of the adsorbent is determined by the difference between the desorbed conditioned level and the full adsorption isotherm of the adsorbent. Therefore, the conditioning effect must be considered when sizing the adsorbent bed. The conditioning effect can require up to twice as much adsorbent in the bed. Since regeneration should occur only about every 8 or 16 operating hours, the capacity of the bed(s) can be determined by the concentration of VOC, the air flow rate, the weight of adsorbent in the bed(s), the type of adsorbent, and the "working capacity" of the adsorbent. In this way, the "working capacity" can have a significant effect on the cost of installing, operating, and maintaining an adsorber.

Absorbers. Absorption is a process used to remove a gaseous pollutant by dissolving it in a liquid. Water is the most commonly used absorbent fluid. As the gas stream passes through the liquid, it becomes mixed in the solution in much the same way that sugar is absorbed in a glass of water when stirred. Absorption is commonly used to recover products or to purify gas streams that have high concentrations of organic compounds. However, a major disadvantage of the absorption process is the amount of wastewater created. Critics of column absorbers and scrubbers quickly note that the wastewater created by such devices convert a problem of air pollution into one of water pollution.

Absorption is a process used to remove a gaseous pollutant by dissolving it in a liquid.

Absorption equipment is designed to mix as much of the gas and liquid as possible. Absorbers are often referred to as scrubbers and are commercially available in many forms. The most commonly used absorption equipment includes spray towers, packed columns, spray chambers, and venturi scrubbers.

The packed-column absorber has a column filled with an inert (non-reactive) substance, such as plastic or ceramic that increases the liquid surface area in which the absorbing liquid and the pollutant gas can mix. The inert material helps to maximize the absorption capability of the column. As the gas and liquid are introduced at opposite ends of the column, a counter-current flow is produced that serves to efficiently mix the two substances. In general, absorbers can achieve removal efficiencies greater than 95 percent.

The Packed Column absorber introduces gas and liquid at opposite ends of the column. A counter-current flow is produced that serves to efficiently mix the two substances. In practice, absorbers can achieve removal efficiencies greater than 95 percent.

Packed-bed scrubbers consist of a chamber containing layers of variously shaped packing material, such as

Raschig rings, spiral rings, or Berl saddles that provide a large surface area for liquid-particle contact. The packing is held in place by wire mesh retainers and supported by a plate near the bottom of the scrubber. Scrubbing liquid is evenly introduced above the packing and flows down through the bed. The liquid coats the packing and establishes a thin film, but it should be noted that the pollutant to be absorbed must be soluble in the fluid. In vertical designs (packed towers), the gas stream flows up the chamber (countercurrent to the liquid). Some packed beds are designed horizontally for gas flow across the packing (cross-current) (EPA, 1998).

Physical absorption depends on the properties of the gas stream and the liquid solvent, such as density and viscosity, as well as specific characteristics of the pollutant(s) in the gas and the liquid stream (i.e., diffusivity, equilibrium solubility). These properties are temperature dependent, so that lower temperatures generally favor absorption of gases by the solvent. Absorption is also enhanced by greater contacting surface, higher liquid-gas ratios, and higher concentrations in the gas stream (EPA, 1991). Chemical absorption may be limited by the rate of reaction; although the rate-limiting step is typically the physical absorption rate, not the chemical reaction rate (EPA, 1996a; EPA, 1996b).

VOC Control. Absorption is a commonly applied operation in chemical processing. It is used as a raw material and/or a product recovery technique in separating and purifying gaseous streams containing high concentrations of organics (i.e., in natural gas purification and coke by-product recovery operations). In absorption, the organics in the gas stream are dissolved in a liquid solvent. The contact between the absorbing liquid and the vent gas is accomplished in counter current spray towers, scrubbers, or packed or plate columns (EPA, 1995).

The use of absorption, as the primary control technique for organic vapors, is subject to several limiting factors. One factor is the availability of a suitable solvent. The VOC must be soluble in the absorbing liquid and, even then for any given absorbent liquid, only the VOCs that are soluble can be removed. Some common solvents that may be used to trap volatile organics include water, mineral oils, or other non-volatile petroleum oils. Another factor that affects the suitability of absorption for organic emissions control is the availability of vapor/liquid equilibrium data for the specific organic/solvent system in question. Such data are necessary for the design of absorber systems; however, they are not readily available for uncommon organic compounds.

The solvent chosen to remove the pollutant(s) should have a high solubility for the vapor or gas, low vapor pressure, low viscosity, and should be relatively inexpensive. Water is used to absorb VOCs having relatively high water solubilities. Amphiphilic block copolymers added to water can make hydrophobic VOCs dissolve in water. Other solvents such as hydrocarbon oils are also used for VOCs that have low water solubilities, though only in industries where large volumes of these oils are available (i.e., petroleum refineries and petrochemical plants) (EPA, 1996).

Another consideration in the application of absorption as a control technique is the treatment or disposal of the material removed from the absorber. In most cases, the scrubbing liquid containing the VOC is regenerated in an operation known as stripping, in which the VOC is desorbed from the absorbent liquid, typically at elevated temperatures and/or under vacuum. The VOC is then recovered as a liquid by a condenser (EPA, 1995).

In packed-bed scrubbers, the gas stream is forced to follow a circuitous path through the packing material, on which much of the PM impacts. The liquid on the packing material collects the PM and flows down the chamber towards the drain at the bottom of the tower. A mist eliminator (also called a “de-mister”) is typically positioned above/after the packing and scrubbing liquid supply. Any scrubbing liquid and wetted PM entrained in the exiting gas stream will be removed by the mist eliminator and returned to drain through the packed bed. In a packed-bed scrubber, high PM concentrations can clog the bed; hence the limitation of these devices to streams with relatively low dust loadings.

Plugging is another serious problem for packed-bed scrubbers because the packing is more difficult to access and clean than other scrubber designs. Mobile-bed scrubbers are available that are packed with low-density plastic spheres that are free to move within the packed bed. These scrubbers are less susceptible to plugging because of the increased movement of the packing material. In general, packed-bed scrubbers are more suitable for gas scrubbing than PM scrubbing because of the high maintenance requirements for control of PM (EPA, 1998).

The suitability of gas absorption as a pollution control method is generally dependent on the following factors:

1) Availability of suitable solvent; 2) Required removal efficiency; 3) Pollutant concentration in the inlet vapor; 4) Capacity required for handling waste gas; and, 5) Recovery value of the pollutant(s) or the disposal cost of the unrecoverable solvent (EPA, 1996a). Packed-bed scrubbers are typically used in the chemical, aluminum, coke and ferroalloy, food and agriculture, and chromium electroplating industries. These scrubbers have had limited use as part of flue gas desulfurization (FGD) systems, but the scrubbing solution flow rate must be carefully controlled to avoid flooding (EPA, 1998; EPA, 1991).

When absorption is used for VOC control, packed towers are usually more cost effective than impingement plate towers. However, in certain cases, the impingement plate design is preferred over packed-tower columns when either internal cooling is desired, or where low liquid flow rates would inadequately wet the packing (EPA, 1992).

Absorbers are primarily used to control inorganic fumes, vapors, and gases (i.e., chromic acid, hydrogen sulfide, ammonia, chlorides, fluorides, and SO_2), volatile organic compounds (VOCs); particulate matter (PM), including PM less than or equal to 10 micrometers (µm) in aerodynamic diameter (PM_{10}), PM less than or equal to 2.5µm in aerodynamic diameter ($PM_{2.5}$); and hazardous air pollutants (HAPs) in particulate form (PMHAP). Absorption is also widely used as a raw material and/or product recovery technique in separating and purifying gaseous waste streams containing high concentrations of VOCs, especially water-soluble compounds such as methanol, ethanol, isopropanol, butanol, acetone, and formaldehyde (Croll Reynolds, 1999).

Hydrophobic VOCs can be absorbed using an amphiphilic block copolymer dissolved in water. However, as an emission control technique, it is much more.

Condensers. Condensation is the process of reducing a gas or vapor to a liquid. Any gas can be reduced to a liquid by lowering its temperature and/or increasing its pressure. So a condenser removes gaseous pollution from the air by lowering the temperature of the gas to a point at which it becomes condensed and collected as a liquid. A simple example of the condensation process occurs when droplets of water form on the outside of a cold glass of water. The cold temperature of the glass causes water vapor from the surrounding air to become transformed into a liquid state on the surface of the glass. Condensation can be achieved through either increasing pressure or by extracting heat from the system, but heat extraction is the most commonly used technique. Condensers are also used to recover valuable products from a waste stream. Like scrubbers, condensers produce wastewater that must be disposed. Consequently, condensers are generally used in combination with other control devices.

Contact and surface condensers dispose of waste gas by freezing or condensing the pollutant into a more solid substance.

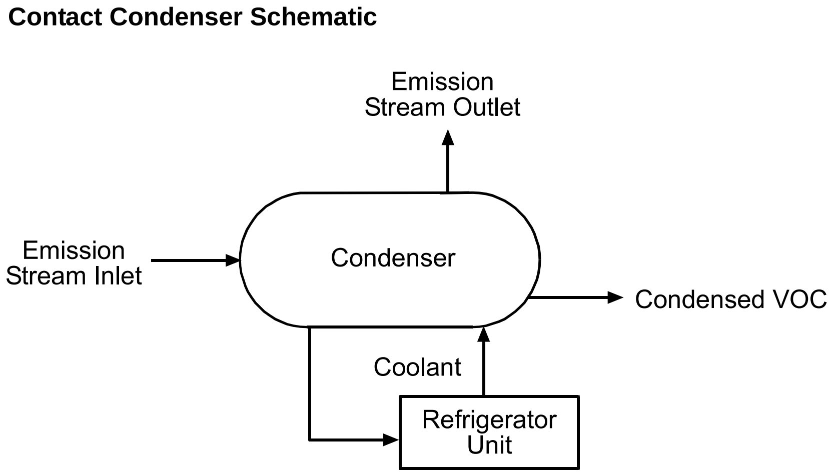


Figure 10-7. Contact Condenser

Condensers fall into to basic categories; contact (see Figure 10-7) and surface condensers (see Figure 10-8). In a contact condenser the coolant and vapor stream are physically mixed. They leave the condenser as a single exhaust stream. In a surface condenser, the coolant is separated from the vapors by tubular heat transfer surfaces, and leave the device by separate exits. Surface condensers are commonly called shell and tube heat exchangers. The temperature of the coolant is increased, so the devices also act as heaters. Condensers of this type generally yield removal efficiencies of 50 to 95 percent, depending on the design and application.

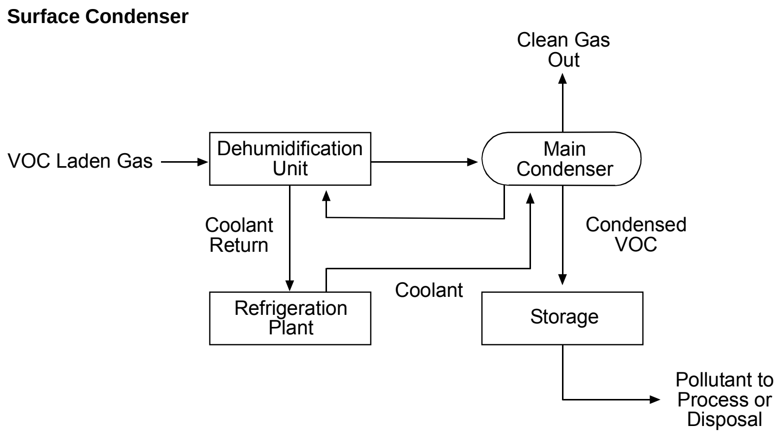


Figure 10-8. Surface Condenser

Inorganic Gas Control. Water is the most common solvent used to remove inorganic contaminants. Pollutant removal may be improved by enhancing the chemistry of the absorbing solution, so that it reacts with the pollutant. Caustic solution (sodium hydroxide, NaOH) is the most common scrubbing liquid used for acid-gas control (i.e., HCl, SO_2, or both), though sodium carbonate ($Na_2 CO_3$) and calcium hydroxide (slaked lime, $Ca[OH]_2$) are also used. When the acid gases are absorbed into the scrubbing solution, they react with alkaline compounds to produce neutral salts. The rate of absorption of the acid gases is dependent on the solubility of the acid gases in the scrubbing liquid (EPA, 1996a; EPA, 1996b).

Sulfur Dioxide Emissions Controls

Various technologies exist that have been designed to remove SO_2 from flue gas produced by electricity generating plants. These technologies represent a varying degree of commercial readiness. Some can claim tens of thousand of hours of operational experience, while others have only recently been demonstrated at commercial plants. The term *flue gas desulfurization* has traditionally referred to wet scrubbers that remove sulfur dioxide (SO_2) emissions from large electric utility boilers (mainly coal combustion). However, because of the requirement to control acid emissions from industrial boilers and incinerators and the evolution of different types of acid control systems, the terms *FGD*, *acid gas* or *acid rain control* are used interchangeably to categorize a wide variety of control system designs. FGD systems are also used to reduce SO_2 emissions from process plants such as smelters, acid plants, refineries, and pulp and paper mills.

Commercially available FGD technologies can "conventionally" be classified as *once-through* and *regenerable*, depending on how sorbent is treated after it has sorbed SO_2 (Scrubber Myths & Realities). In once-through technologies, the SO_2 is permanently bound by the sorbent, which must be disposed of as a waste or utilized as a by-product (i.e., gypsum). In regenerable technologies, the SO_2 is released from the sorbent during the regeneration step and may be further processed to yield sulfuric acid, elemental sulfur, or liquid SO_2. The regenerated sorbent is recycled in the SO_2 scrubbing step. Both once-through and regenerable technologies can be further classified as *wet* or *dry*. In wet processes, wet slurry waste or by-product is produced, and flue gas leaving the absorber is saturated with moisture. In dry processes, dry waste material is produced and flue gas leaving the absorber is not saturated with moisture.

Depending on process configuration and local market conditions at the plant site, once-through wet FGD processes can produce slurry waste or salable by-product. This waste/by-product must be dewatered in some fashion prior to disposal or sale (in case of a salable by-product). The "conventional" classification of FGD processes is shown in Figure 10-9.

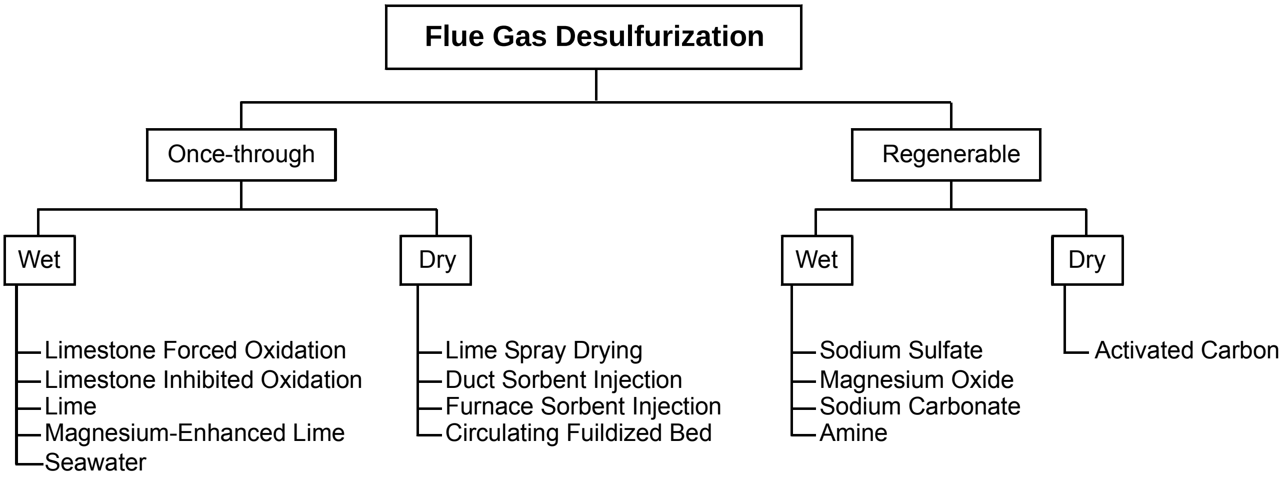


Figure 10-9. Flue Gas Desulfurization Technology Tree

Wet FGD Technologies

In wet FGD processes flue gas contacts alkaline slurry in an absorber. The absorber may take various forms (spray tower or tray tower), depending on the manufacturer and desired process configuration. However, the most often-used absorber application is the counterflow vertically oriented spray tower. A diverse group of wet FGD processes have evolved to take advantage of particular properties of various sorbents and/or by-products. All wet FGD processes discussed here are once through (i.e., non-regenerable).

A generalized flow diagram of a baseline wet FGD system is shown in Figure 10-10. SO_2-containing flue gas is contacted with limestone slurry in an absorber. Limestone slurry is prepared in two consecutive steps. First, limestone is crushed into a fine powder with a desired particle size distribution. This takes place in a crushing station; i.e., ball mill (fine crushing maximizes the dissolution rate of a given limestone).

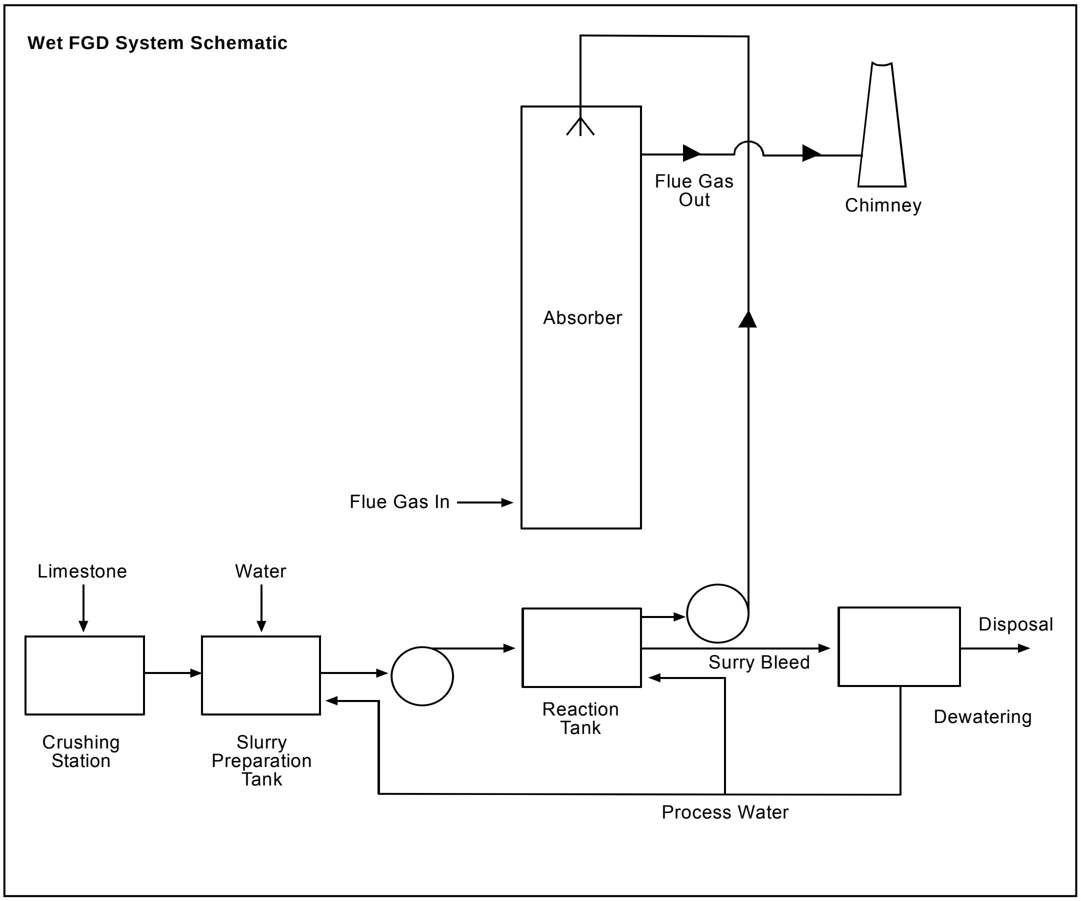


Figure 10-10. Baseline Wet FGD System

Next, this fine powder is mixed with water in a slurry preparation tank. Sorbent slurry from this tank is then pumped into the absorber reaction tank.

As mentioned before, the absorber is most often a counterflow tower with flue gas flowing upwards, while limestone slurry is sprayed downwards by an array of spray nozzles. In the absorber, SO_2 is removed by both sorption and reaction with the slurry. Reactions initiated in the absorber are completed in a reaction tank, which provides retention time for finely ground limestone particles to dissolve and to react with the dissolved SO_2. The slurry is re-circulated from the reaction tank into the absorber. Reaction products from the reaction tank are pumped to the waste handling equipment, which concentrates the waste. From the waste handling equipment, the concentrated waste is sent for disposal (ponding or stacking) or, alternatively, processed to produce a saleable gypsum (calcium sulfate dihydrate) by-product.

Limestone Forced Oxidation

Over the years, limestone forced oxidation (LSFO), which minimizes scaling problems in the absorber, has become the preferred process for wet FGD technology worldwide. Gypsum scale typically forms via natural oxidation when the fraction of calcium sulfate in the slurry (slurry oxidation level) is greater than 15%. In LSFO, scaling is prevented by forcing oxidation of calcium sulfite to calcium sulfate by blowing air into the reaction tank (in-situ oxidation), or into an additional hold tank (ex-situ oxidation). The gypsum thus formed is removed as usual and, as a con-sequence, the concentration of gypsum in the slurry recycled to the absorber de-creases. In LSFO systems used to produce saleable gypsum, nearly complete oxidation (over 99%) is achieved.

Limestone-Inhibited Oxidation

Another wet limestone process, de-signed to control oxidation in the absorber, is limestone-inhibited oxidation (LSIO). In LSIO, emulsified sodium thiosulfate ($Na_2S_2O_3$) is added to the limestone slurry feed to prevent the oxidation to gypsum in the absorber by lowering the slurry oxidation level to below 15%. In general, solids dewatering is more difficult in LSIO, compared to LSFO, due to the higher level of sulfites. The

LSIO chemistry is particularly efficient in applications with high sulfur coals.

Lime and Magnesium-Lime

The lime process uses calcitic lime slurry in a counterflow spray tower. This slurry is more reactive than limestone slurry, but is more expensive. Magnesium-enhanced lime (MEL) is a variation of the lime process in that it uses a special type of lime. MEL is able to achieve high SO_2 removal efficiencies in significantly smaller absorber towers compared to calcitic lime. Additionally, MEL needs less slurry, com-pared to LSFO, for the same level of SO_2 removal.

Dry FGD Technologies

LSD for the control of SO_2 emissions is used for sources that burn low- to medium-sulfur coal, with occasional applications for coals with higher sulfur content. Some issues that limit the use of spray dryers with high-sulfur coals include the In these technologies, SO_2 containing flue gas contacts alkaline (most often lime) sorbent. As a result, dry waste is produced that is generally easier to dispose of than waste produced from wet FGD processes. The sorbent can be delivered to flue gas in an aqueous slurry form [lime spray drying (LSD)] or as a dry powder [duct sorbent injection (DSI), furnace sorbent injection (FSI), and circulating fluidized bed (CFB)]. LSD and CFB require dedicated absorber vessels for sorbent to react with SO_2, while in DSI and FSI, new hardware requirements are limited to sorbent delivery equipment. In dry processes, sorbent re-circulation may be used to in-crease its utilization. The potential impact of chloride contained in the coal on the spray dryer performance, and the ability of the existing particulate control device to handle the increased loading and achieve the required efficiency.

The LSD is shown schematically in Figure 9-16. Hot flue gas mixes in a spray dryer vessel with a mist of finely atomized fresh lime slurry. Fresh lime slurry is prepared in a slaker (most often a ball mill) at a nominal concentration of solids. Rotary atomizers or two-fluid nozzles are used to finely disperse lime slurry into flue gas. Typically, spray dryers are operated at lime stoichiometry of 0.9 for low sulfur coals and 1.3 to 1.5 for high sulfur coals. Simultaneous heat and mass transfer between alkali in a finely dispersed lime slurry and SO_2 from the gas phase result in a series of reactions and a drying of process waste. The amount of water fed into the spray dryer is carefully controlled to avoid complete saturation of the flue gas. While a close approach to adiabatic saturation (from 10 to 15 C for coal-derived flue gas) is required to achieve high SO_2 removal, complete saturation impairs operation of a spray dryer because of wet solids adhering to vessel walls and within the particulate collector. Primary reactions in the spray dryer are as follows:

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 \bullet + \tfrac{1}{2}\ H_2O + \tfrac{1}{2}\ H_2O$$

$$Ca(OH)_2 + SO_3 + H_2O \rightarrow CaSO_3 \bullet + 2\ H_2O$$

$$CaSO_3 + \tfrac{1}{2}O_2 \rightarrow CaSO_4$$

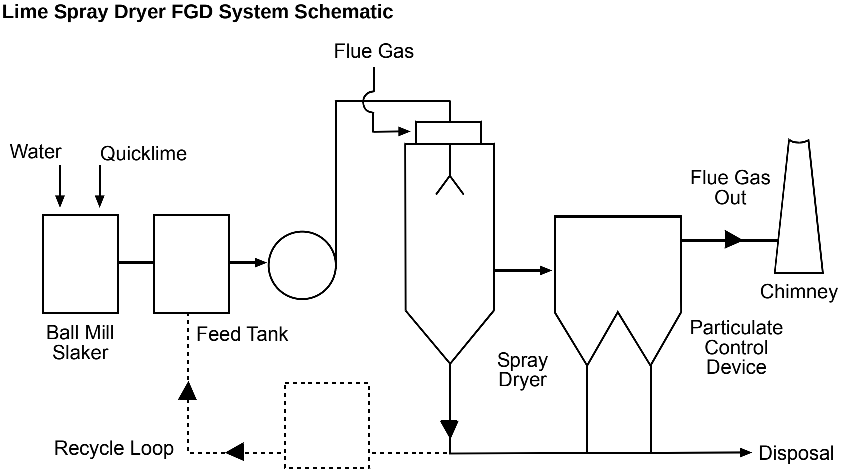


Figure 10-11. Lime Spray Dryer FGD System

Some of the dry reaction product solids are collected at the bottom of the spray dryer. The remaining solids, suspended in the flue gas, travel to the particulate control device where the separation occurs. For a process configuration where the particulate control device is a baghouse, a significant additional SO_2 removal may occur in the filter cake on the surface of bags. Dry solids from the particulate control device's hopper and from the bottom of the spray dryer are disposed of. The extent of alkali usage in a spray dryer is limited by its available residence time for a gas-solid reaction. Typical residence time in a spray dryer is 8 to 12 seconds. In order to increase sorbent utilization, part of the dry solids from the bottom of the spray dryer and the particulate collector's hopper are sent to the recycle solids slurry tank. The recirculated stream (shown with a broken line in Figure 10-11) contains partially reacted alkali from previous passes through the system. The additional exposure of a sorbent to SO_2 afforded by the recycle promotes increased sorbent utilization.

Lime Spray Drying

LSD is most often used by sources that burn low-to-medium-sulfur coal. In a spray dryer, simultaneous heat and mass transfer between alkali in a finely dispersed aqueous lime slurry and SO_2 result in a series of reactions and a drying of process waste. Studies indicate that most SO_2 capture in the spray dryer occurs when the sorbent is still moist. Therefore, deliquescent additives may be used to increase the duration of time in which the sorbent remains moist. Duct Sorbent Injection DSI is intended to provide SO_2 control directly in the flue gas duct between the air pre-heater and the particulate control device. In this process, dry sorbent (most often hydrated lime) is injected into the flue gas downstream of the boiler's air pre-heater. Water is injected separately from the sorbent. Fly ash, reaction products and any unreacted sorbent are collected in the particulate control device.

Furnace Sorbent Injection

In FSI, dry sorbent is injected directly into the furnace where temperatures are between 950 and 1000° C. Sorbent particles (most often calcium hydroxide, some-times calcium carbonate) decompose and become porous solids with high surface area. Calcium sulfate and any remaining unreacted sorbent, leave the furnace with the flue gas and are captured, as solids in a particulate collection device.

Circulating Fluidized Bed

In CFB, dry sorbent (hydrated lime) is contacted with a humidified flue gas in a CFB. The bed provides a long contact time between the sorbent and flue gas because sorbent passes through the bed several times. CFB is characterized by good SO_2 mass transfer conditions from the gas to the solid phase. However, due to a higher particulate matter concentration downstream of the fluidized bed, improvements to the existing electrostatic precipitator may be needed to maintain the required particulate emission levels.

Regenerable FGD Technologies

Regenerable FGD technologies find only marginal application in the U.S. and throughout the world. These processes involve comparatively high operation and maintenance (O&M) costs, relative to other FGD processes, and the return from sale of the product does not offset a significant portion of the increased process cost. Regenerable FGD technologies discussed in the report include four wet processes (sodium sulfite, magnesium oxide, sodium carbonate, and amine) and one dry process (activated carbon). These processes produce a concentrated stream of SO_2 that can be used for sulfuric acid production.

Performance

An estimate of the SO_2 reduction performance of FGD technologies was obtained by examining the design SO_2 removal efficiencies reported in the CoalPower3 Database. These data reflect that the median design efficiency for all units using wet limestone processes is about 90%. However, advanced, state-of-the-art wet scrubbers are capable of achieving SO_2 removal efficiencies of over 95%. High velocity LSFO, with state-of-the-art design options, is reportedly capable of removing more than 99.6% of SO_2 under test conditions.

The data also reflect that the median design efficiency for all units using LSD is 90%. However, recent LSD applications, installed between 1991 and 1995 have design SO_2 removal efficiencies between 90 and 95%. It is useful to examine the improvement in performance of wet limestone and LSD processes over the period of their application. Figure 9-16 shows ranges and medians of design SO_2 removal efficiency for pertinent populations of wet limestone FGD and LSD installations in each of the last three decades. A steady improvement in design SO_2 removal efficiency is evident for these processes. This improvement may be due, in part, to more stringent SO_2 control requirements. However, the trends do reflect that the SO_2 removal efficiencies for the processes considered have, improved with time.

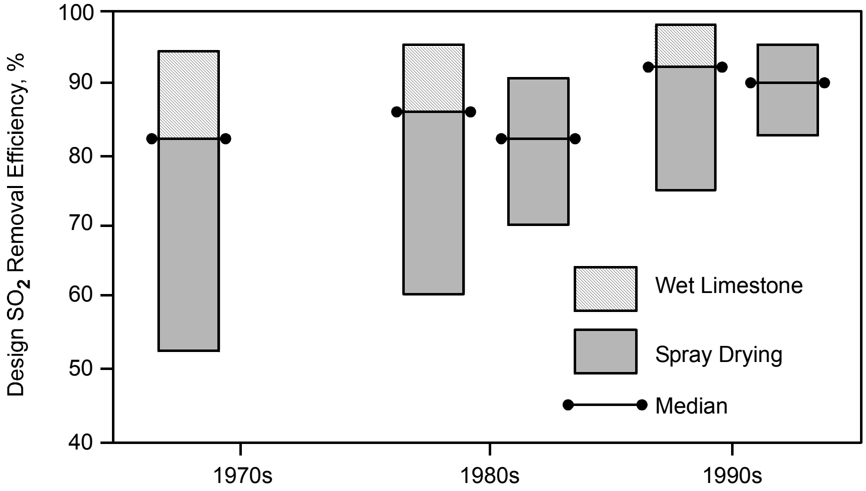


Figure 10-12. Improvement in Design Efficiency of FGD Technologies of Interest

Several technical options are available for upgrading the SO_2 removal performance of existing wet FGD installations. Some of the important options include increasing the reactivity of the limestone slurry with organic acid addition, installing a perforated tray or other device to increase mass transfer, and reducing the amount of flue gas that is bypassed. Several advanced design, process, and sorbent options are also available for new wet FGD installations. Some of these include using large capacity modules, increasing flue gas velocity in the absorber, and buffering with organic acid. These advanced options are capable of providing high SO_2 removal and/or increased operational efficiency.

Nitrogen Oxides (NOx) Emissions Control

NOx represent a family of seven compounds. EPA regulates only nitrogen dioxide (NO2) as a surrogate for this family of compounds because it is the most prevalent form of NOx in the atmosphere that is generated by anthropogenic (human) activities. NO_2 is not only an important air pollutant by itself, but also reacts in the atmosphere to form ozone (O_3) and acid rain. Automobiles and other mobile sources contribute about half of the NOx that is emitted. Electric power plant boilers produce about 40% of the NOx emissions from stationary sources. Additionally, substantial emissions are also added by such anthropogenic sources as industrial boilers, incinerators, gas turbines, reciprocating spark ignition and Diesel engines in stationary sources, iron and steel mills, cement manufacture, glass manufacture, petroleum refineries, and nitric acid manufacture. Biogenic or natural sources of nitrogen oxides include lightning, forest fires, grass fires, trees, bushes, grasses, and yeasts. These various sources produce differing amounts of each oxide.

In combustion, there are three opportunities for NOx formation.

1. Thermal NOx. The concentration of “thermal NOx” is controlled by the nitrogen and oxygen molar concentrations and the temperature of combustion. Combustion at temperatures well below 1,300°C (2,370°F) forms much smaller concentrations of thermal NOx.

2. Fuel NOx. Fuels that contain nitrogen (i.e., coal) create “fuel NOx” that results from oxidation of the already-ionized nitrogen contained in the fuel.

3. Prompt NOx. Prompt NOx is formed from molecular nitrogen in the air combining with fuel in fuel-rich conditions, which exist to some extent, in all combustion. This nitrogen then oxidizes along with the fuel and becomes NOx during combustion, just like fuel NOx. The abundance of prompt NOx is disputed by the various writers of articles and reports—probably because they each are either considering fuels intrinsically containing very large or very small amounts of nitrogen, or are considering burners that are intended to either have or not have fuel-rich regions in the flame.

NOx abatement and control technology is a relatively complex issue. Combustion sources all have NOx in a large flow of flue gas, while nitric acid manufacturing plants and pickling baths try to contain the NOx. Wet scrubbers (absorbers) can control NOx emissions from acid plants and pickling, and can use either alkali in water, water alone, or hydrogen peroxide as the liquid that captures the NOx.. The wet scrubber operates by liquid flowing downward by gravity through a packing medium, opposed by an upward flow of gas. Scrubbers operate on the interchange of substances between gas and liquid. This requires that the height of the absorber, type of packing, liquid flow, liquid properties, gas properties, and gas flow should collectively cause a scrubber to have the desired control efficiency. (EPA, 1999).

For combustion sources, abatement and emission control principles is typically expressed as the Destruction or Removal Efficiency (DRE) that each successful technology is capable of achieving. The effectiveness of pollution prevention measures in reducing NO and NO_2 generation also is expressed in terms of relative DRE; i.e., the amount NOx generation is reduced by using a prevention technology compared to NOx generation when not using that technology.

Many new combustion systems incorporate NOx prevention methods into their design and generate far less NOx then similar but older systems. As a result, considering DRE (even a relative DRE) for NOx may be inappropriate. Comparing estimated or actual NOx emissions from a new, well-designed system to NOx emitted by a similar well-controlled and operated older system may be the best way of evaluating how effectively a new combustion system minimizes NOx emissions. Table 9-5 lists principles or methods that are used to reduce NOx. Basically there are six principles, with the seventh being an intentional combination of some subset of the six.

Method 1. Reducing Temperature. Reducing combustion temperature means avoiding the stoichiometric ratio (the exact ratio of chemicals that enter into reaction). Essentially, this technique dilutes calories with an excess of fuel, air, flue gas, or steam. Combustion controls use different forms of this technique and are different for fuels with high and low nitrogen content. Control of NOx from combustion of high nitrogen content fuels (i.e., coal) can be understood by the net stoichiometric ratio. Control of the NOx from combustion of low nitrogen fuels (such as gas and oil) can be seen as lean versus rich fuel/air ratios. Either way, this technique avoids the ideal stoichiometric ratio because this is the ratio that produces higher temperatures that generate higher concentrations of thermal NOx.

Table 10-3. NOx Control Methods[a,b]

Abatement or Emission Control Principle or Method	Successful Technologies	Pollution Prevention Method (P2) or Add on Technology (A)
1. Reducing peak temperature	Flue Gas Recirculation (FGR)	P2
	Natural Gas Reburning	P2
	Low NOx Burners (LNB)	P2
	Combustion Optimization	P2
	Burners Out Of Service (BOOS)	P2
	Less Excess Air (LEA)	P2
	Inject Water or Steam	P2

	Over Fire Air (OFA) Air Staging Reduced Air Preheat Catalytic Combustion	P2 P2 P2 P2
2.Reducing residence time at peak temperature	Inject Air Inject Fuel Inject Steam	P2 P2 P2
3. Chemical reduction of NOx	Fuel Reburning (FR) Low NOx Burners (LNB) Selective Catalytic Reduction (SCR) Selective Non-Catalytic Reduction (SNCR)	P2 P2 A A
4. Oxidation of NOx with subsequent absorption	Non-Thermal Plasma Reactor Inject Oxidant	A A
5. Removal of nitrogen	Oxygen Instead Of Air Ultra-Low Nitrogen Fuel	P2 P2
6. Using a sorbent	Sorbent In Combustion Chambers Sorbent In Ducts	A A
7. Combinations of these Methods	All Commercial Products	P2 and A

[a] EPA 1999 November
[b] XONON

Method 2. Reducing Residence Time. Ignition or injection timing can do reducing residence time at high combustion temperatures with internal combustion engines. It can also be done in boilers by restricting the flame to a short region in which the combustion air becomes flue gas. This is immediately followed by injection of fuel, steam, more combustion air, or recirculating flue gas. This short residence time at peak temperature keeps the vast majority of nitrogen from becoming ionized. This bears no relationship to total residence time of a flue gas in a boiler.

Method 3. Chemical Reduction of NOx. This technique provides a chemically reducing (i.e., reversal of oxidization) substance to remove oxygen from nitrogen oxides. Examples include Selective Catalytic Reduction (SCR), which uses ammonia, Selective Non-Catalytic Reduction (SNCR) that use ammonia or urea, and Fuel Reburning (FR). Non-thermal plasma, an emerging technology, when used with a reducing agent, chemically reduces NOx.

Method 4. Oxidation of NOx. This technique intentionally raises the valence of the nitrogen ion to allow water to absorb it (i.e., it is based on the greater solubility of NOx at higher valence). This is accomplished either by using a catalyst, injecting hydrogen peroxide, creating ozone within the air flow or injecting ozone into the air flow. Non-thermal plasma, when used without a reducing agent, can be used to oxidize NOx. A scrubber must be added to the process to absorb N_2O_5 emissions to the atmosphere

Method 5. Removal of nitrogen from combustion. This is accomplished by removing nitrogen as a reactant either by: (1) using oxygen instead of air in the combustion process; or (2) using ultra-low nitrogen content fuel to form less fuel NOx. Eliminating nitrogen by using oxygen tends to produce a rather intense flame that must be subsequently and suitably diluted. Although Method 2 can lower the temperature quickly to avoid forming excessive NOx, it cannot eliminate nitrogen oxides totally if air is the quench medium. Hot flue gas heats the air that is used to quench it and this heating generates some thermal NOx. This method also includes reducing the net excess air used in the combustion process because air is 80% nitrogen. Using ultra-low-nitrogen content fuels with oxygen can nearly eliminate fuel and prompt NOx. (Chambers, B.,1993)

Method 6. Sorption, both adsorption and absorption. Treatment of flue gas by injection of sorbents (such as ammonia, powdered limestone, aluminum oxide, or carbon) can remove NOx and other pollutants (principally sulfur). There have been successful efforts to make sorption products a marketable commodity. This kind of treatment has been applied in the combustion chamber, flue, and baghouse. The use of carbon as an adsorbent has not led to a marketable product, but it is sometimes used to limit NOx emissions in spite of this. The sorption method is often referred to as using a dry sorbent, but slurries also have been used. This method uses either adsorption or absorption followed by filtration and/or electrostatic precipitation to remove the sorbent.

Method 7. Combinations of these methods. Many of these methods can be combined to achieve a lower NOx concentration than can be achieved alone by any one method. For example, a fuel-rich cyclone burner (Method 1) can be followed by fuel reburn (Method 3) and over-fire air (Method 1). This has produced as much as a 70% reduction in NOx (O'Conner D., Hines, R. and Facchiano, T.) Other control technologies that are intended to primarily reduce concentrations of sulfur also strongly affect the nitrogen oxide concentration. For example, the SOx-NOx-ROx-Box (SNRB) technology uses a limestone sorbent in the flue gas from the boiler to absorb sulfur. This is followed by ammonia injection and SCR using catalyst fibers in the baghouse filter bags. The sulfur is recovered from the sorbent and the sorbent regenerated by a Claus process. This has demonstrated removal of up to 90% of the NOx along with 80% of the SOx (EPA,1999).

NAME ______________________________________ DATE _______________ SCORE_________

CHAPTER 10 CONTROL OF EMISSIONS FROM STATIONARY SOURCES

Multiple Choice

Directions: *Read each question and choose the best answer. Write the letter of your answer in the space provided.)*

1. The following are all principles used to control gaseous emissions, **except** _______.

a. impaction
b. condensation
c. absorption
d. adsorption
e. combustion

1. ________

2. Which of the following control devices might be effectively used to control gaseous emissions?

a. Fabric filters
b. Absorption spray tower
c. Impingement plate scrubber
d. Process boiler
e. Multiple cyclone

2. ________

3. Absorbers collect gaseous pollutants by ________.

a. trapping them in a carbon reagent
b. transferring them from the gas stream into the liquid reagent
c. freezing or condensing the pollutant into a more solid substance
d. heating the pollutant to hasten disposal through combustion
e. catalytic means that consumes the pollutant

3. _______

4. Contact condensers are ________.

a. used to control nitrogen oxide emissions
b. control devices in which coolants come in direct contact with vapors
c. sometimes referred to as shell and tube heat exchangers
d. control devices that are always used before adsorbers for VOC control
e. allow exhaust gases and coolant to exit separately

4. _______

Matching

Directions: *Match each of the following advantages and disadvantages with the proper control technology.*

Control Technology

A. Scrubbers
B. Surface and Shell Condensers
C. Adsorbers

________ **5.** Can be used for condensable gases and vapors.

________ **6.** Collects both gas and particles while neutralizing corrosive gases.

________ **7.** For collecting a mixture of volatile organic gases.

________ **8.** Effectively collects various organic gases found in the electronic and petrochemical operations

________ **9.** Effluents can create water pollution problems.

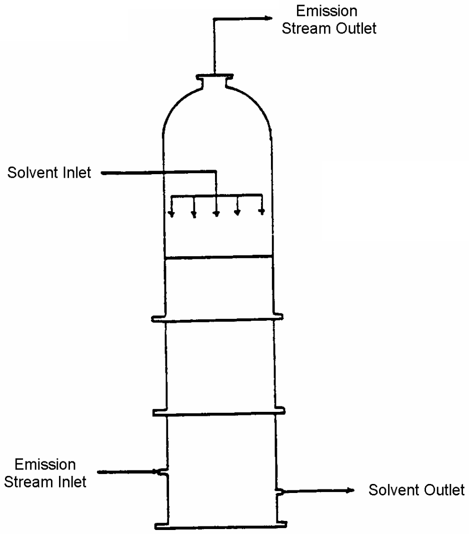
________ **10.** Effectively collects a wide variety of organic gases and is typically used by the computer industry.

Control Technology Identification

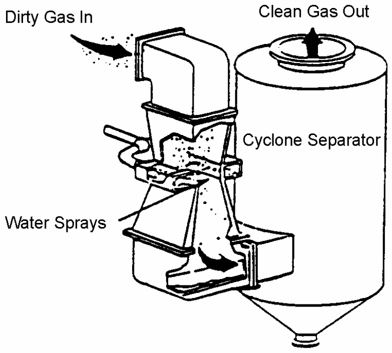
Directions: *Match the control technology with the device that is displayed and answer the questions in the spaces provided.*

- **A. Electrostatic Precipitator**
- **B. Catalytic Incinerator**
- **C. Contact Condenser**
- **D. Carbon Adsorber**
- **E. Cyclone Collector**
- **F. Elevated Flare System**
- **G. Packed Column Absorber System**
- **H. Fabric Filter**
- **I. Thermal Incinerator**
- **J. Adsorption System**
- **K. Settling Chamber**
- **L. Venturi Scrubber**

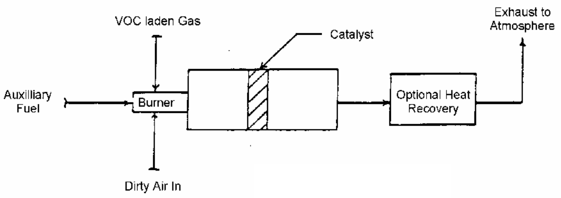
11. _______



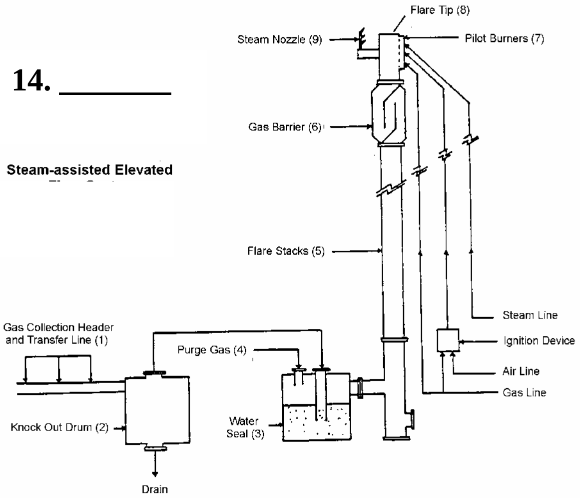
12. _______



13. _______



14. _______



REVIEW ANSWERS

No.	Answer
1.	A
2.	D
3.	B
4.	B
5.	B
6.	A, B
7.	C
8.	B
9.	C
10.	C
11.	G
12.	L
13.	B
14.	F

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CHAPTER 11

Control of Mobile Sources

Lesson Goal

Demonstrate an understanding of the basic principles, equipment, and methods used to control particulate and gaseous emissions generated by mobile and stationary sources of air pollution by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Describe the basic principles, equipment, and methods used to control particulate and gaseous emissions generated by mobile sources of air pollution.
2. Describe how to control particulate and gaseous emissions from mobile sources.
3. Identify how emissions from mobile sources contribute to the problem of air pollution.
4. Discuss how mobile sources of emissions were historically controlled.
5. Identify potential future controls of mobile source emissions.
6. Describe the operating principles and technologies used to control nitrogen oxide (NO_X), hydrocarbon (HC), and carbon monoxide (CO) emissions.
7. Explain the advantages and disadvantages of using electric cars for the purpose of achieving cleaner air.
8. List and explain the sources of vehicle emissions.
9. Describe how vehicle emissions produce or exacerbate the effects of criteria pollutants.
10. List several advances in control technology that may be available in the future.
11. Construct a timeline of milestones that describe control measures of mobile source pollution.

12. Describe the U.S. EPA's vehicle testing program.

Recommended Reading: Godish, Thad, "Motor Vehicle Emissions Control," *Air Quality*, 3rd Edition, New York: Lewis, 1997, pp. 287-308.

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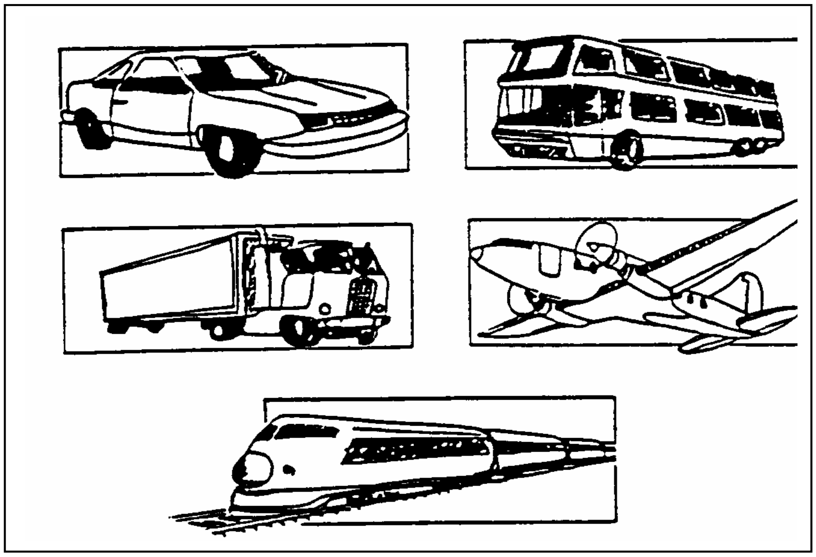
Control of Mobile Sources

In the United States, mobile sources, which include automobiles, motorcycles, trucks, buses and off-road vehicles, are currently estimated to be responsible for about half of all emissions released into the air. The specific pollutant categories include 47 percent of the volatile organic compound (VOC) emissions, 56 percent of the nitrogen oxides (NOx) emissions, approximately 80 percent of the carbon monoxide (CO) emissions and 50 percent of the hazardous air pollutants in urban areas.

Approximately 9,000 tons of carbon monoxide is deposited into the air each day in Los Angeles County.

Although steady progress has been made in controlling mobile emissions at the individual vehicle level over the last 40 years through the use of effective technology in areas such as engine controls, exhaust catalysts, and improved fuels, a full resolution of the problem has not yet come to fruition. In addition, the problem of mobile source air pollution is exacerbated by the growth in the number of vehicles, their use patterns and the failure of emission controls in a small, but significant portion of vehicles, which has offset part of the overall anticipated emissions gains. For example, fixed emitters, mobile sources can be effectively managed by additional control technology, changes in operating practices, better commuter choices and fuel reformulations.



People have grown dependent on millions of jobs created by industry and the valuable goods and services it provides. Likewise, transportation has become an indispensable part of our lifestyle. For this reason, sweeping controls on mobile sources of air pollution must be balanced against preserving a quality of life that depends so heavily on the use of transportation.

Mobile sources of air pollution are inextricably woven into the fabric of our lives. Each day we either use or receive a product delivered in some form by rail, ship, or air. Cars, buses, and trucks line our roads and highways. Thousands of people have discovered the recreational use of motorcycles or other special purpose, all-terrain vehicles, boats and airplanes. The need to control mobile sources of air pollution weighs heavy against a culture so dependent on rapid forms of transportation. The development of effective means to control air pollution by mobile sources requires a thorough understanding of the emission source and combustion process. Therefore, the purpose of this chapter is to characterize the types of mobile sources of air pollution, discuss trends in their use, and examine potential alternatives.

Sources of Automobile Emissions:

- *Exhaust pipe emissions*
- *“Blowby Gases”*
- *Carburetor emissions*
- *Evaporative losses during refueling*

Mobile Sources of Pollution

Milestones in Auto Emissions Control. Air pollution and cars were first linked in 1952 by Haagen-Smit, a chemistry professor and researcher at the California Institute of Technology in Pasadena, who determined that mobile sources were to blame for a large part of the smoggy skies over Los Angeles. He also observed that in spite of early smoke control measures, residents still smelled a curious bleaching-solution odor in the air, and suffered severe eye irritation on smoggy days. After analyzing samples of air collected in five-liter flasks from Southland refineries and using them to create artificial "Haagen-smog" in the laboratory, Haagen-Smit announced in 1952 that ozone, the primary ingredient in smog, was not directly emitted from tailpipes or smokestacks, but was created in the atmosphere. Driven by sunlight, a photochemical reaction combined hydrocarbons from oil refineries and the partially unburned exhaust of automobiles with nitrogen oxides, a combustion byproduct, to form ozone.

At the time, typical new cars were emitting nearly 13 grams per mile hydrocarbons (HC), 3.6 grams per mile nitrogen oxides (NOx), and 87 grams per mile carbon monoxide (CO).

Since then, the Federal Government has set standards to bring down levels of these pollutants, and the auto industry has responded by developing new emission control technologies. The current Federal certification standards for exhaust emissions from cars are 0.25 gram per mile HC**,** 0.4 gram per mile NOx, and 3.4 grams per mile CO. The standard for evaporative HC emissions is 2 grams per test. The improvements came about as a result of a series of steps:

1964 California requires minimal emission control systems on 1966 model cars.

1965 Congress requires minimal emission controls on all automobiles produced in 1968 and later.

1970 Congress adopts the first major Clean Air Act, establishes the U.S. Environmental Protection Agency (EPA), and gives the new Agency broad responsibility for regulating motor vehicle pollution. The clean air law calls for 90 percent reductions in automotive emissions. New cars must meet a 0.41 gram per mile HC standard and a 3.4 grams per mile CO standard by 1975; NOx emissions must be reduced to 0.4 gram per mile by 1976*. The law also directs EPA to set health-based “National Ambient Air Quality Standards” for six pollutants, all of which are present in auto emissions to some degree. (*Note: The NOx standard was later revised. See 1977.)

1971 New cars must meet evaporative emission standards for the first time; charcoal canisters to trap gasoline vapors appear.

1972 Exhaust gas recirculation (EGR) valves appear as auto- makers strive to meet NOx standards.

1974 Congress delays the HC and CO standards until 1978 and sets interim standards at the request of the auto industry. Congress sets Corporate Average Fuel standards.

1975 The first catalytic converters appear, and with them, unleaded gasoline, in response to HC and CO standards.

1977 Congress amends the Clean Air Act. At the request of automakers, the HC standard is delayed until 1980 and the CO standard until 1981. The NOx standard is delayed until 1981 and then is relaxed to 1 gram per mile.

1981 New cars meet the amended Clean Air Act standards for the first time. Sophisticated three-way catalysts with on-board computers and oxygen sensors appear in most new cars.

1982 Inspection and Maintenance (I/M) programs are established in 64 cities nationwide, requiring passenger vehicles to undergo periodic testing for malfunctioning emission control systems.

1985 EPA adopts stringent emission standards for diesel-powered trucks and buses to take effect in 1991 and 1994.

1989 EPA for the first time sets fuel volatility limits aimed at reducing evaporative emissions.

1990 EPA imposes strict limits on diesel fuel sulfur content to help buses and trucks meet the 1985 emission standards (which become effective in the early 1990's). Congress amends the Clean Air Act to require further reductions in HC, CO, NOx, and particulate emissions. The amendments also introduce a comprehensive set of programs aimed at reducing pollution from motor vehicles. This include: lower tailpipe standards; more stringent emission testing procedures; expanded I/M programs; new vehicle technologies and clean fuels programs; transportation management provisions; and possible regulation of emissions from non-road vehicles.

1991 EPA promulgates lower tailpipe standards for HC and NOx as required by the 1990 Clean Air Act. These standards take effect beginning with 1994 models.

1992 Standards setting emission limits for carbon monoxide at cold temperatures (20ºF) are established for the first time. Oxygenated gasoline is introduced in cities with high CO levels.

1994 Phase-in of tighter tailpipe standards for light-duty vehicles begins. Enhanced Inspection and Maintenance programs begin in some polluted cities. Trucks and buses must meet stringent diesel particulate emission standards. New cars must be equipped with on-board diagnostic systems.

1995 Reformulated gasoline provisions take effect in the nation's smoggiest cities and in other areas that voluntarily join the program.

1996 Phase-in begins for cleaner vehicle standards and technologies required by the 1990 Clean Air Act. All new vehicles (1996 model year cars and light trucks) must meet new tailpipe and cold-temperature carbon monoxide standards.

1997 Clean-fuel fleet programs begin in ozone and carbon monoxide nonattainment areas in 19 states.

2001 Second phase of the Fleets and California Pilot clean fuels programs begin.

Automobiles and Emissions. Motor vehicles are by far the greatest mobile source of air pollution. In 1999, on road vehicles produced 29 percent of all VOC emissions, down from 42 percent in 1970. Pollutants are generated in three main areas of an automobile. These main areas of emissions are classified as evaporative, exhaust, and refueling losses. Evaporation of gasoline is a source of volatile organic compounds (VOC's) comparable in magnitude to the exhaust VOC's emissions.

The four categories of evaporative volatile organic compounds emissions from motor vehicle fuel systems are: (1) diurnal emissions, (2) running losses, (3) hot soak emissions and (4) refueling. Diurnal emissions occur due to evaporation of gasoline, which increases as the temperature rises during the day, heating the fuel tank and venting its vapor.

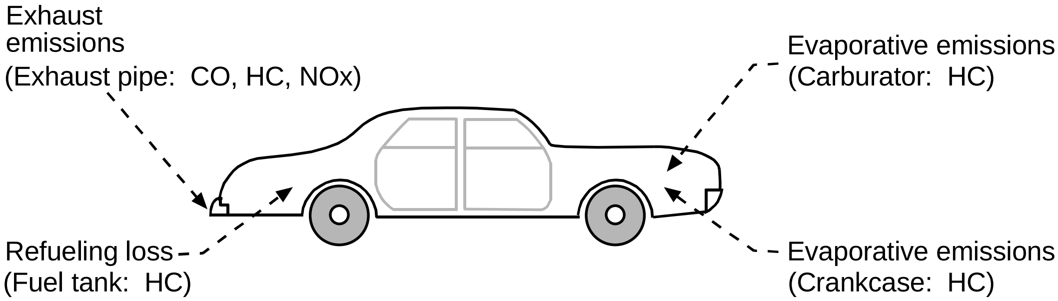


Figure 11-1. Emissions and Emission Sources of Light-Duty Vehicles.
(Source: Godish, Thad, *Air Quality*, Lewis: New York, 1997, p. 288.)

Running losses occur as the gasoline vapors are vented from the fuel tank while the automobile is operating and the fuel in the tank becomes hot. Hot soak emissions are released when the engine is turned off after operation and remains hot for a period of time after, which the gasoline continuing to evaporate until the engine reaches ambient temperatures.

Exhaust pipe emissions are the most significant source of automobile pollution. Exhaust accounts for approximately 90% of the pollutant emitted by an automobile.

However, the most significant automobile pollution is from the combustion of gas that is vented through the exhaust pipe. The engine exhaust accounts for approximately 90% of the pollutant emitted by an automobile. Pollutants in the exhaust gas of a spark–ignition (SI) engine consists mainly of unburned hydrocarbons, carbon monoxide, and varying quantities of nitrogen oxides, particulates, and hazardous compounds (i.e. benzene, acetaldehyde, formaldehyde and 1,3-butadiene). Nitric oxides and carbon monoxide are formed during the combustion process and leave the engine with other combustion products (i.e. carbon dioxide and water vapor).

The formation of nitric oxide (NO) occurs due the high temperature and pressure break down of oxygen and nitrogen atoms with the engine combustion from the induced air. These atoms recombine to form NO, NO_2 and N_2O. Together they are referred to as NOx. SI engines are typically high in NO and are estimated to be over 95%, although under some conditions N_2O may constitute over 10% of the total NO_X emissions.

The production of NO is also dependant on the peak temperatures produced during the combustion process. However, the quantity of NOx formed is also related to other variables such as pre-combustion conditions, fuel to air ratio, and flame speed. As SI engine combustion efficiency increases, accompanying higher chamber temperatures, which enhance the formation of NO_x. However, NO_x can be significantly reduced by utilization of rich air-fuel mixtures as shown in Figure 10-2. Retarding or delaying the spark, so that ignition occurs late in the compression stroke can also reduce NOx production. This reduces the time available for the production of higher temperatures and consequentially results in decreased NO_x formation. Prior to ignition as the piston in an SI engine moves upward the air–fuel is compressed. Lowering engine compression ratio, which is the relationship between the initial and final combustion chamber volumes, produces lower combustion chamber temperatures. This in effect lowers NO_x emissions. This also facilitates the use of lower octane unleaded fuels that are required for the efficient operation of catalytic converters.

Carbon monoxide (CO) like unburned hydrocarbons form as mostly as a result of the incomplete oxidation of carbon in the fuel to carbon dioxide the degree of which is mostly determined by the air to fuel (A/F) ratio. Carbon monoxide production from the engine combustion reaction increases sharply with decreasing air to fuel ratios, since not enough oxygen is available to complete the oxidation of the air/fuel mixture. The main variable for CO formation is whether the engine is running lean, at stoichiometric, or rich (see Figure 10-1). Excursions into fuel-rich mixtures while operating during cold starts and transient periods are responsible for the majority of the carbon monoxide emissions in newer SI engines. CO emissions in newer spark-ignition engines can be adequately controlled by maintaining combustion at close to stoichiometric and with the use of a catalyst control system.

Carbon monoxide (CO) formation results from the incomplete oxidation of carbon in the fuel to carbon dioxide.

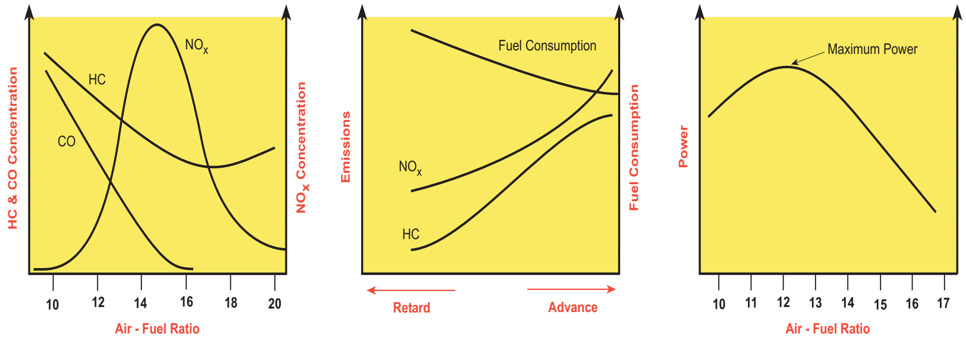


Figure 11-2. Exhaust Emissions Related to Automobile Engine Operating Parameters (Source: Godish, Thad, *Air* Quality, New York: Lewis, 1997, pp. 289, 292, 297.)

Unburned hydrocarbons (HC) result from a number of processes in which fuel escapes the cylinder combustion during flame passage. Approximately 1.5 to 2.0 percent of the gasoline fuel leaves an SI engine unoxidized. Many critical processes can affect how the fuel escapes the engines' combustion reaction. These processes include quenching of the flame near cold cylinder walls, called quench zones, near thin gaps on the combustion chamber or crevices, absorption of fuel on chamber carbon deposits and lubricating oil, and from liquid fuel, particularly at initial start up. The major engine variables that affect the amount of unburned hydrocarbons exiting a SI engine are fuel to air equivalence ratio, cylinder compression ratio, engine speed, and spark timing.

Starting a car cold increases trip emissions compared to starting the car warm. For a 7.5 mile trip by a typical car in 2000, the vehicle emits about 8.7 grams of NO_x and 95.1 grams of CO if the engine is already warm. If, however, the engine is cold, an additional 1.4 grams of NO_x and 37.8 grams of CO are generated. As a result, for a 7.5 mile trip, starting the car cold generates about 16 percent more NO_x and 40 percent more CO than starting the car when it is warm. Volatile organic compounds (VOC) are emitted both from the tailpipe and through fuel evaporation. About 6.3 grams of VOC are emitted from the tailpipe if the engine is warm, and evaporative emissions (during travel and while cooling down) result in 2.3 grams of VOC. Starting the car cold generates another 4.3 grams of VOC.

Linking multiple trips called trip chaining helps reduce emissions by eliminating the cold start. However, on hot summer days, even when a car is parked all day, VOC evaporates from the vehicle's fuel tank and control systems. Approximately 2.6 grams of VOC per day are emitted simply from having the car parked all day.

Refueling losses of gasoline occur each time that a vehicle is refueled. The amount of gasoline vapors in the automobile fuel tank increases as the quantity of liquid gasoline in the fuel tank decreases. Use of conventional nozzles allows these vapors, in an amount by volume equal to the quantity of gasoline dispensed, to escape from the automobile fuel tank through the fill pipe opening into the atmosphere. At the same time, the gasoline withdrawn from the service station storage tank would be replaced by an equal volume of air, permitting additional transformation of liquid gasoline to vapor in the service station tank.

Evaporative losses of gasoline occur each time a vehicle is refueled.

Stage II vapor recovery systems collect the gasoline vapors that are forced out of the automobile fill pipe opening with a vapor recovery nozzle. The collected vapors enter the front end of the nozzle either through flexible bellows positioned around the nozzle spout, or a port on the outside of the nozzle spout through which a vacuum is introduced to assist in the vapor collection. The vapors then travel through the vapor passage in the body of the nozzle, vapor hose, underground piping and go into the service station's underground storage tank (see Figure 10-3).

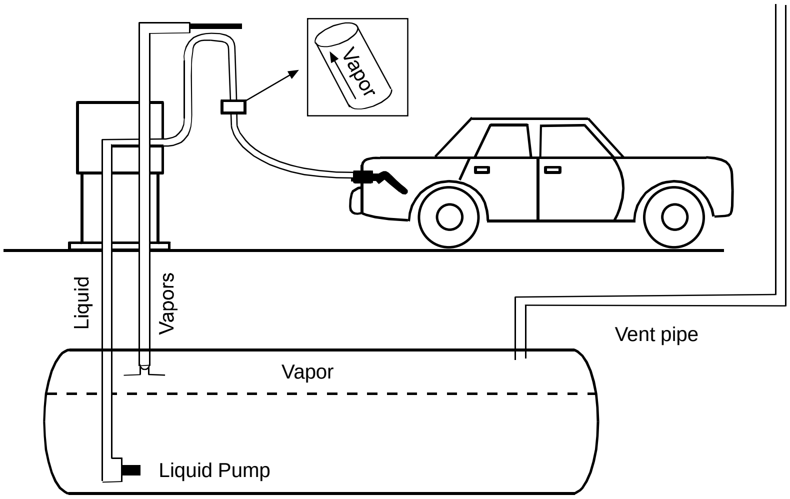
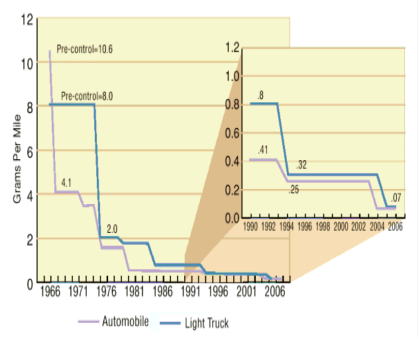


Figure 11-3. Stage II Gasoline Vapor Recovery System

Federal Emission Standards The Clean Air Act of 1963 and its subsequent amendments set federal emissions control standards for all new cars and light trucks sold in the United States. The most recent Clean Air Act Amendments in 1990 established more restrictive "Tier 1" emissions standards, which became effective in 1994. The CAAA also required EPA to study whether more stringent Tier 2 standards were needed to meet the NAAQS. In 1999, EPA determined that new standards were needed and cost-effective. Starting in 2004, all classes of passenger vehicles, including sport utility vehicles and light trucks, will have to comply with new average tailpipe standards of 0.07 grams per mile for nitrogen oxides.

In December 1999 EPA announced new engine and gasoline standards commonly known as Tier II. The standards were designed to reduce the emissions from new passenger cars and light trucks, including pickup trucks, minivans, and sport-utility vehicles. Beginning in 2004, the nation's refiners and importers of gasoline will have to manufacture gasoline with sulfur levels capped at 300 parts per million (ppm), approximately a 15 percent reduction from the current industry average of 347 ppm. By 2006, refiners will meet a 30 ppm average sulfur level with a maximum cap of 80 ppm. The Tier II regulations are predicted to decrease NO_X emissions by 61 percent, and VOC emissions by 24 percent between 2004 and 2030.

Control of Automobile Emissions Emission control of automobiles initially used minor engine adjustments and low cost devices, but has since escalated into major design considerations and substantial costs. Control commenced with the introduction of the positive crankcase ventilation (PCV) control system in 1961. During the internal combustion process, a “blowby” gas of unburned fuel and exhaust combustion products is produced that seeps past the incomplete seal of the piston ring. Crankcase emissions of this type have been controlled by the development of a relatively simple and inexpensive technology called positive crankcase ventilation (PCV). This control technique recirculates fugitive gases back into the



combustion chamber for reburning (Wark and Warner, 1976).

The emission reductions of the 1970's came about because of fundamental improvements in engine design, plus the addition of charcoal canisters to collect hydrocarbon vapors and exhaust gas recirculation valves to reduce nitrogen oxides. The advent of "first generation" catalytic converters in 1975 significantly reduced hydrocarbon and carbon monoxide emissions. In addition, the use of converters provided a huge indirect benefit as well. Because lead inactivates the catalyst, 1975 saw the widespread introduction of unleaded gasoline.

The next major milestone in vehicle emission control technology came in 1980-81. In response to tighter standards, manufacturers equipped new cars with even more sophisticated emission control systems. These systems generally included a "three-way" catalyst (which converts carbon monoxide and hydrocarbons to carbon dioxide and water, and also helped reduce nitrogen oxides to elemental nitrogen and oxygen), plus an on-board computer and oxygen sensor. This equipment helped optimize the efficiency of the catalytic converter (see Figure 11-4). Provisions of the 1990 Clean Air Act are reducing vehicle emissions even further. Mobile source provisions include even tighter tailpipe standards, increased durability, improved control of evaporative emissions, and computerized diagnostic systems that identify malfunctioning emission controls.

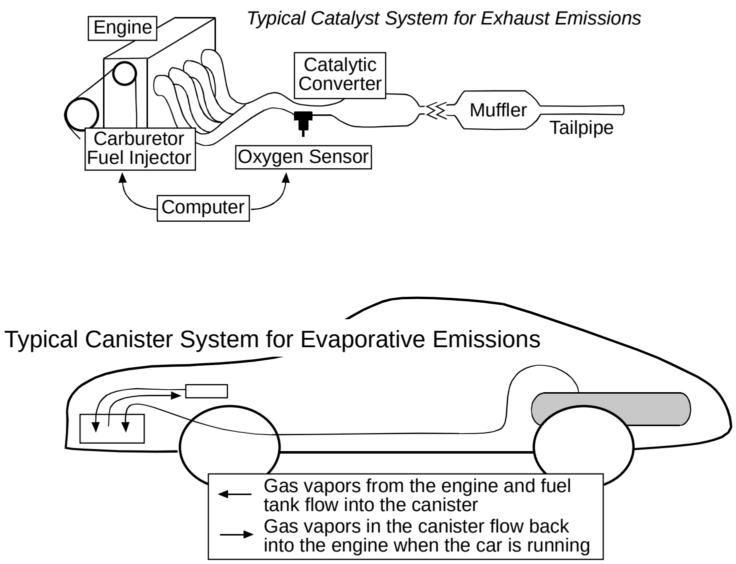
The 1990 Clean Air Act provisions include even tighter tailpipe standards, increased durability, improved control of evaporative emissions, and computerized diagnostic systems that identify malfunctioning emission controls.

The exhaust gas recirculation (EGR) system is one of the most effective ways to reduce NO_x formation. This control method recirculates controlled amounts of exhaust gases back into the intake manifold where it mixes with the fuel and air entering the combustion cycle. These relatively inert exhaust gases (mostly carbon dioxide and water) act as a heat sink and in turn reduce peak combustion temperatures, which lower NO_x production.

Another device utilized in this period to aid in controlling emission with the catalytic converters is the “Thermactor” which is a trade name for the emissions control system known generically as AIR (air injection reaction). The function of the AIR system is to blow fresh air into the exhaust gas stream. There are two benefits of this system: (1) Fresh air blown into the exhaust gas, just downstream of the exhaust ports, provides oxygen (O2) to promote further combustion of any remaining unburned hydrocarbons (HCs) in the exhaust gas and (2) Catalytic converters require additional oxygen to convert the carbon monoxide (CO) and hydrocarbons in exhaust gases into carbon dioxide (CO2) and water (H2O).

Under the Clean Air Act, auto manufactures will build cleaner automobiles and will use cleaner fuels. In order to ensure automobiles are being maintained, an inspection and maintenance (I/M) program is required in more than forty metropolitan areas throughout the United States. Some areas that already have I/M programs are required to enhance (improve) their emission inspection equipment and procedures. Enhanced I/M will provide more realistic measurements of the automobiles emission by using
a method like IM240. This test method measures and utilizes a dynamometer with driving schedules based on EPA's Federal Test Procedure (FTP75), which certifies compliance with federal vehicle emission standards for carbon monoxide (CO), unburned hydrocarbons (HC), and nitrogen oxides (NOx). This equipment will provide simulated conditions similar to being driven instead of a static or sitting parked emission measurement.

Basic Controls for Exhaust and Evaporative Emissions

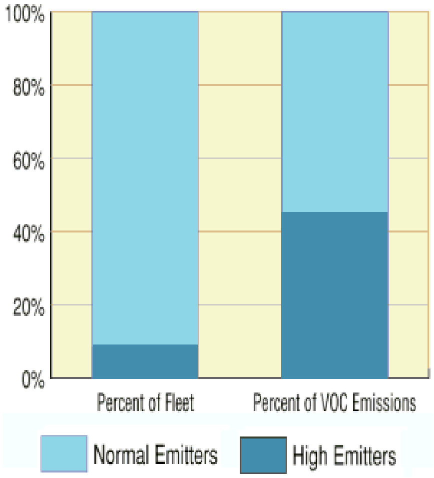


Typical Catalyst System for Exhaust Emissions

Typical Canister System for Evaporative Emissions

Figure 11-4. Basic Controls for SI Engine Exhaust and Evaporative Emissions

Gross Emitters

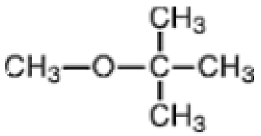


A small percentage of vehicles emit a large percentage of the pollution from on-road vehicles. These "gross emitters" include not only older model vehicles but also some newer cars with poorly maintained or malfunctioning emissions control equipment. As shown in the diagram, it is estimated that less than 10 percent of the vehicle fleet emits approximately 50 percent of the VOC emissions. The same vehicles, however, are not always gross emitters for all criteria pollutants - different 10 percent may be gross emitters for CO, NOx, and others. Additionally, 10-27 percent of the vehicles failing inspection never end up passing the State Inspection and Maintenance tests.

Reformulated Gasoline and Alternative Fuels

The 1990 Clean Air Act also addresses cleaner fuels. One way to reduce air pollution from cars and trucks is to use a gasoline that is designed to burn cleaner. This cleaner burning gasoline, called reformulated gasoline or RFG, is required by the Clean Air Act in cities with the worst smog pollution, but other cities with smog problems may choose to use RFG. The federal RFG program was introduced in 1995; RFG is currently used in 17 states and the District of Columbia. About 30 percent of gasoline sold in the U.S. is reformulated. Each oil company prepares its own formula that must meet federal emission reduction standards.

The first phase of the RFG program was designed to reduce the air pollution that causes smog by 64,000 tons per year in the areas that use RFG, compared to conventional gasoline—the equivalent of eliminating the smog-forming emissions from over 10 million vehicles. Phase II RFG replaced Phase I in 2000 and is designed to reduce smog pollutants by an additional 41,000 tons per year in RFG areas, for a combined equivalent of eliminating the smog-forming emissions from about 16 million vehicles. The RFG program also reduces emissions of toxic air pollutants such as benzene, a known human carcinogen. Phase I and Phase II RFG combined reduce toxic pollutants by about 24,000 tons per year in RFG areas, the equivalent of eliminating the toxic emissions from over 13 million vehicles.



Methyl Tertiary-Butyl Ether
(MTBE)

In the Clean Air Act, Congress specified that RFG contain two percent by weight oxygen. MTBE (methyl tertiary butyl ether) and ethanol are the two most commonly used oxygenates that increase oxygen content to gasoline for more complete combustion in engines. MTBE has been used in U.S. gasoline at low levels since 1979 to replace lead alkalis (ethyl and tetramethy lead) as an octane enhancer (helps prevent the engine from "knocking") and since 1992 has been used at higher concentrations in some gasoline. MTBE (methyl tertiary-butyl ether) is a chemical compound that is manufactured by the chemical reaction of methanol and isobutylene. MTBE is produced in very large quantities (over 200,000 barrels per day in the U.S. in 1999) and is almost exclusively used as a fuel additive in motor gasoline. Oxygen helps gasoline burn more completely, reducing harmful tailpipe emissions from motor vehicles. In one respect, the oxygen dilutes or displaces gasoline components such as aromatics (i.e., benzene) and sulfur. In another, oxygen optimizes the oxidation during combustion. Oil companies decide which substance to use to meet the law’s requirements. Most refiners have chosen to use MTBE over other oxygenates primarily for its blending characteristics and for economic reasons.

At room temperature, MTBE is a volatile, flammable and colorless liquid that dissolves rather easily in water. Leaking storage tanks are the number one cause of gasoline contamination of water. Small spills and improper disposal are also sources of contamination. Many chemicals in gasoline—including MTBE—can be harmful in water. MTBE is highly soluble and travels faster and farther in water than other gasoline components.

Ethanol (CH_3CH_2OH) the other common oxygenate, is a group of chemical compounds whose molecules contain a hydroxyl group, -OH, bonded to a carbon atom. Ethanol is produced by fermenting and distilling starch crops that have been converted into simple sugars. Feedstocks for producing ethanol include corn, barley and wheat. Ethanol can also be produced from "cellulosic biomass" such as trees and grasses and is called bioethanol. In some areas of the United States, ethanol is blended with gasoline to form an E10 blend (10% ethanol and 90% gasoline), but it can be used in higher concentrations such as E85 or E95. Original equipment manufacturers produce flexible-fuel vehicles that can run on E85 or any other combination of ethanol and gasoline.

EPA promotes and expands the use of environmentally beneficial alternative fuels. A variety of alternative fuels are available and can be used to combat different air pollution problems:

Liquefied petroleum gas (LPG). A fossil-fuel derivative composed of 95 percent propane and 5 percent butanes. It produces lower CO emissions, but NOx emissions may be higher.

Natural Gas. A fuel that can be in compressed (CNG) or liquefied (LNG) form. The CNG form, more common in the transportation sector, is stored in high-pressure cylinders. CNG generates lower CO and VOC emissions than conventional gasoline, and lower NO_x and PM than diesel fuels.

Methanol. Wood alcohol made from natural gas, coal, or biomass.

Ethanol. Grain alcohol made from corn, sugarcane or woody biomass. Ethanol blends may reduce CO emissions, but their effect on ozone is negligible.

Electricity. Electric vehicles may be powered by batteries charged at home or at charging stations with electricity from power plants. They have no tailpipe emissions; overall emissions depend on power plant energy sources.

Hydrogen. A clean-burning fuel that can be produced from coal, natural gas, oil, solar, or wind energy. A vehicle operating on a fuel cell, which generates electricity by harnessing the reaction of hydrogen and oxygen to make water, produces no CO or VOC emissions and extremely low NOx emissions. Vehicle/engine design is a critical factor affecting emissions from alternative fueled vehicles.

Hybrid vehicles switch from one power source to the other continuously, depending on the engine load. A hybrid electric vehicle uses a high-energy-density battery and small internal combustion engine. The in-use emissions of the hybrid electric vehicle depend on fuel used in the internal combustion engine-most typically diesel, gasoline, or CNG.

Clean fuels have a number of inherent properties that make them cleaner than conventional gasoline. In general, these fuels emit less volatile organic compounds (VOCs), and the VOCs they do emit are less reactive (slower to form ozone) and less toxic. Emissions from electricity, natural gas, or alcohol-powered vehicles can be as much as 90 percent lower in toxics and ozone-forming VOCs than emissions from vehicles fueled with conventional gasoline. Use of clean fuels could also help slow atmospheric buildup of carbon dioxide, a "greenhouse gas" that contributes to the potential for global warming. Combustion of any carbon-based fuel produces carbon dioxide. But the overall impact of a given fuel on global warming depends on how the fuel is made. In general, fuels produced from biomass (crops, trees, etc.) and from natural gas result in less carbon dioxide accumulation than fuels made from petroleum or coal.

Providing states with tools, such as benefits models, State Implementation Plan Credits, and the Clean Fuels Fleet program, also encourages utilization of clean fuel vehicles. EPA also coordinates with the Department of Energy and Department of Transportation so that their Energy Policy Act and Transportation Equity Act of the 21st Century programs promote alternative fuels and vehicles having the greatest environmental gains.

Although the internal combustion engine represents one of the most profound changes to our lifestyle of this century, the attendant environmental effects are now abundantly evident. In the same manner that the internal combustion engine replaced horse- drawn buggies, it is likely that the automobile will one day be made obsolete by a new technology. However, until that day arrives, the most realistic methods of reducing automobile exhaust emissions include car-pooling, increased use of public transportation, and the use of cleaner burning fuels.

Table 11-1. Summary Table of Alternative Fuel Advantages and Disadvantages

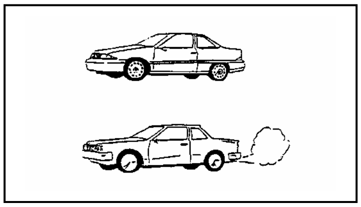
Fuel	Advantages	Disadvantages
Electricity	• Potential for zero vehicle emissions • Power plant emissions easier to control • Can recharge at night when power demand is low	• Current technology is limited • Higher vehicle cost; lower vehicle range, performance • Less convenient refueling
Ethanol	• Excellent automotive fuel • Very low emissions of ozone-forming hydrocarbons and toxins • Made from renewable sources • Can be domestically produced	• High fuel cost • Somewhat lower vehicle range
Methanol	• Excellent automotive fuel • Very low emissions of ozone-forming hydrocarbons and toxins • Can be made from a variety of feedstocks, including renewables	• Fuel could initally be imported • Somewhat .lLower vehicle range
Natural Gas (Methane)	• Very low emissions of ozone-forming hydrocarbons, toxins, and carbon monoxide • Can be made from a variety of feedstocks, including renewables • Excellent fuel, especially for fleet vehicles	• High fuel cost • Lower vehicle range • Less convenient refueling
Propane	• Cheaper than gasoline today • Most widely available clean fuel today • Somewhat lower emissions of ozone-forming hydrocarbons and toxics • Excellent fuel, especially for fleet vehicles	• Cost will rise with demand • Limited supply • No energy security or trade balance benefits
Reformulated Gasoline	• Can be used in all cars without changing vehicles or fuel distribution system • Somewhat lower emissions of ozone-forming hydrocarbons, nitrogen oxides, and toxics	• Somewhat higher fuel cost • Fewer energy security or trade benefits

Diesel Engines. Diesel PM consists of three primary constituents: unburned carbon particles, which make up the largest portion of the total PM; the soluble organic fraction (SOF), which consists of unburned hydrocarbons that have condensed into liquid droplets or have condensed onto unburned carbon particles; and sulfates, which result from oxidation of fuel-borne sulfur in the engine's exhaust. Diesel engines have made great progress in lowering engine-out emissions from 6.0 g/bhp-hr NOx and 0.6 g/bhp-hr PM in 1990 to 4.0 g/bhp-hr NOx and 0.1 g/bhp-hr PM in 1998. These reductions came initially with improvements to

Diesel engines have made great progress in lowering engine out emissions by improving diesel combustion and fuel systems.

combustion and fuel systems. The introduction of electronic fuel systems in the early 1990s also allowed lower NOx and PM levels without sacrificing fuel economy. This, and with increasing fuel injection pressures, have been the primary technologies that have allowed emission levels to be reduced to current levels.

Further engine-out NOx reductions to the levels necessary to comply with the 2004 standard of 2.5 g/bhp-hr NOx+NMHC will come primarily from the addition of cooled exhaust gas recirculation (EGR). This method recirculates a portion of the exhaust back to the intake manifold where it is drawn into the combustion chamber. There may be more than one factor involved in the reduction of NOx by EGR, including the heat capacity increase from the CO_2 in the EGR and oxygen dilution from the lower O_2 found in EGR. Some may argue that the change in heat capacity is not significant, however. The O_2 dilution theory holds that lowering the O_2 concentration lowers O_2 partial pressure which in turn lowers its propensity to oxidize N_2 to NO and NO_2 (NOx) during the combustion process.



Several exhaust after treatment devices have been developed to control diesel PM constituents – the diesel oxidation catalyst (DOC), and the many forms of particulate filters, or traps. DOCs have been shown to be durable in use, but they effectively control only the SOF portion of the total PM which, especially on today's engines, constitutes only around 10 to 30 percent of the total PM. Therefore, the DOC alone does not address our PM concerns sufficiently.

At this time, only the PM trap is capable of providing the level of control sought by the proposed PM standards. In the past, the PM trap has demonstrated high trapping efficiency, but regeneration of the collected PM has been a serious challenge. The PM trap works by passing the exhaust through a ceramic or metallic filter to collect the PM. The collected PM, mostly carbon particles, but also the SOF portion, must then be burned off the filter before the filter becomes plugged. This burning off of collected PM is referred to as “regeneration,” and can occur either:

- on a periodic basis by using base metal catalysts, or an
- active regeneration system such as an electrical heater, a fuel burner, or a microwave heater; or,
- on a continuous basis by using precious metal catalysts.

Uncatalyzed diesel particulate traps demonstrated high PM trapping efficiencies many years ago, but the level of the PM standard was such that it could be met through less costly “in-cylinder” control techniques. Also, the regeneration characteristics were not dependable. As a result, some systems employed electrical heaters or fuel burners to improve on regeneration, but these complicated the system design and still did not provide the durability and dependability required for HD diesel applications.

Off-Road Vehicles and Equipment Emissions. EPA has set increasingly stringent emission standards for highway cars and trucks since the early 1970s. After making much progress in controlling highway emissions, attention has now been given to the wide variety of non-road engines, which also contribute significantly to air pollution. "Non-road" is a term that covers a diverse collection of engines, equipment, vehicles, and vessels.

Sometimes referred to as "off-road" or "off-highway," the non-road category includes outdoor power equipment, recreational vehicles, farm and construction machinery, lawn and garden equipment, marine vessels, locomotives, aircraft, and many other applications. Until the mid-1990s, very few of these engines faced any kind of emission standards. The 1990 amendments to the Clean Air Act directed EPA to study the contribution of non-road engines to urban air pollution, and regulate them if they contributed to air quality problems. In 1991, EPA published a report showing that non-road equipment emitted large amounts of oxides of nitrogen (NOx), hydrocarbon (HC), carbon monoxide (CO) and particulate matter (PM). In general, non-road engines had total emissions almost as high as highway engines. In the case of particulate matter, non-road emissions were significantly higher than highway emissions.

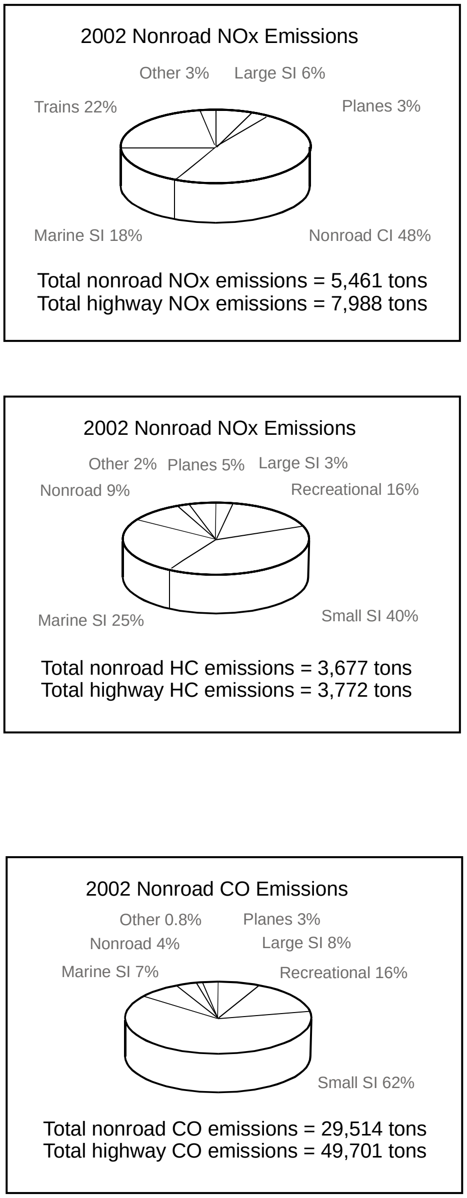


Fig. 10-5. Non-road CO Emissions

Airplanes. Another source of mobile air pollution is

Turbojet and gas turbine engines deposit 24 tons of carbon monoxide into the atmosphere each day.

turbojet and gas turbine powered aircraft. When compared with automobile emissions, the exhaust produced by aircraft is relatively small. Aircraft emissions contribute only about one percent of NOx emissions and six percent of PM emissions nationwide from mobile sources. Some cities with a lot of airport traffic see a more pronounced effect from these engines and the impact on communities near major airports can be substantial.

Although the concentrations of nitrogen oxides, hydrocarbons, and particulates in aircraft emissions are not significantly different from those emitted by motor vehicles, aircraft emissions are more noticeable. The skies are continually crisscrossed with the residue left by the exhaust trails of jet aircraft. Aircraft engines emit great quantities of air pollution because they were designed for high-performance and reliability rather than fuel conservation or other environmental concerns.

Emission standards for gas turbine engines that power civil aircraft have been in place for about 20 years. These engines are used in virtually all commercial aircraft, including both scheduled and freight airlines. The standards do not apply to military or general aviation aircraft. Controls on engine smoke and prohibitions on fuel venting were instituted in 1974 and have been revised several times since then. Beginning in 1984, gas turbine engines must comply with limits on hydrocarbon emissions per landing and takeoff cycle.

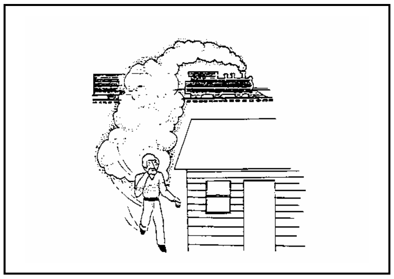
Due to the international nature of the aviation industry, the International Civil Aviation Organization (ICAO) plays an important role in defining uniform emission standards that can be adopted by individual nations. In May 1997, ICAO's NOx and CO emission standards for gas turbine engines were adopted. In addition, a second round of more stringent ICAO NOx standards for gas turbine engines have been proposed for implementation in 2004.

Environmental and public concern about noise and air pollution near airports has resulted in major concessions by the airline industry in finding other ways to reduce air pollution from air transportation. Newer turbojet engines have been redesigned to operate with air-fuel ratios that burn more efficiently and airport operating procedures have been dramatically altered. For example, the amount of time an aircraft spends at idle on the ground has been significantly reduced by strictly controlling their arrival and departure times. Passengers are also transported to and from remotely positioned aircraft by auxiliary ground vehicles, and ground-handling equipment routinely used to tow aircraft to and from the ramp reduce the amount of ground taxi time required of an aircraft.

Airplanes and associated ground-handling equipment contribute greatly to both noise and air pollution in and around airports.

Airlines have also changed the operational flight practices of their pilots and other personnel. For example, flight engineers have reduced the amount of time an aircraft idles for maintenance. Flight patterns have also changed. Today, pilots climb to 3,000 feet as quickly as possible in order to reduce their effect on surrounding communities and have almost completely discontinued the practice of dumping fuel over land and sea in order to achieve better fuel efficiency.

Railroad Locomotives and Marine Engines. Locomotives contribute about 9 percent of NOx emissions and 4 percent of PM emissions from mobile sources. These engines are generally larger and last longer than any land-based, non-road diesel engines. New emission standards will reduce NOx emissions by two-thirds, while HC and PM emissions from these engines will decrease by 50 percent. Three separate sets of emission standards have been adopted, with applicability of the standards dependent on the date a locomotive is first manufactured. The first set of standards (Tier 0) apply to locomotives and locomotive engines originally manufactured from 1973 through 2001, any time they are manufactured or remanufactured. This is a unique feature of the locomotive program, which is critical because locomotives are generally remanufactured 5 to 10 times during their total service lives of 40 years or more.



The second set of standards (Tier 1) apply to locomotives and locomotive engines originally manufactured from 2002 through 2004. These locomotives and locomotive engines will be required to meet the Tier 1 standards at the time of original manufacture and at each subsequent remanufacture.

The final set of standards (Tier 2) apply to locomotives and locomotive engines originally manufactured in 2005 and later. Tier 2 locomotives and locomotive engines will be required to meet the applicable standards at the time of original manufacture and at each subsequent remanufacture.

In recent years, cargo ships have been equipped with emission control equipment technology similar to that used at stationary sources.

Marine vessels vary widely in the sizes and types of engines they use. For the purpose of this discussion, marine engines are divided into three broad categories for setting emission standards: (1) gasoline-fueled outboard engines and personal watercraft; (2) stern driven and inboard gasoline engines; and (3) marine diesel engines. While marine diesel auxiliary engines are included under these marine programs, gasoline-fueled auxiliary engines must meet emission standards that apply to land-based engines.

Future Alternatives

Although no one knows for sure how new technology may revolutionize the transportation industry, it is apparent that innovations in computer technology have given us a better view of the problems and potential answers. Some speculative companies have invested great sums of capital in developing new propulsion systems for light-duty motor vehicles. Their goal is to produce a new, reliable, economic alternative to traditional motor vehicles. These new systems include engines using compressed natural gas, fuel cells and electric-powered vehicles.

Power and distance remain two of the most important obstacles to electric powered vehicle performance.

Stringent air pollution regulatory requirements scheduled to take effect in the next decade may result in the widespread use of electric cars. Battery-operated vehicles are essentially emission-less and use energy more efficiently than other engines. However, the problem that technology has yet to overcome is of the interacting limits of power and distance. Electric vehicles have a relatively short driving range that reduces their usefulness only to local travel. In addition, their performance and acceleration are limited, and fresh replacement batteries for the power supply continue to be very expensive (Godish, 1997). However, critics of the automotive industry see electric cars as a pollution-free alternative to help meet air quality goals and provide transportation in the 21st Century.

EPA has also established the Transportation and Air Quality Center (TRAQ) to provide state and local air quality regulators and transportation planners to assist in areas such as:

- integrating air quality and transportation plans
- creating innovative transportation/air quality solutions
- evaluating programs' emission reduction benefits

TRAQ's web site is www.epa.gov/oms/traq.

NAME ______________________________________ DATE _______________SCORE_________

CHAPTER 11 CONTROL OF EMISSIONS FROM MOBILE SOURCES

Multiple Choice

Directions: Read each question and choose the best answer. Write the letter of your answer in the space provided.

1. Which of the following accounts for approximately 90-92% of all motor vehicle emissions?

a. Exhaust from combustion
b. Crankcase blowby gases
c. Carburetor emissions
d. Evaporative fuel loss (fuel tank)
e. Fugitive emissions (carburetor) **1.**_________

2. Automobile hydrocarbon emissions were first identified as a major source of air pollution in a study conducted by the California Institute of Technology in _______.

a. 1936
b. 1948
c. 1952
d. 1961
e. 1963 **2.** ________

3. The most significant pollutants contained in the emissions of automobile vehicle exhaust are _______.

a. carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2)
b. carbon monoxide (CO), lead (Pb), particulate matter (PM_{10})
c. carbon monoxide (CO), sulfur dioxide (SO_2), acid deposition
d. carbon monoxide (CO), lead (Pb), nitrogen oxides (NO_X)
e. carbon monoxide (CO), nitrogen oxides (NO_X), non-methane VOCs **3.** ________

4. The following are effective emission control devices, **except _______**.

a. Positive Crankcase Ventilation (PCV) valves
b. Exhaust Gas Recycle (EGR)
c. Evaporative Emissions Canister
d. Camshaft and Piston Valves
e. Catalytic Converter **4.** _______

5. What test equipment is currently used to measure vehicle emissions?

a. Exhaust Gas Recirculation (EGR) set
b. IM240 test equipment
c. Dual Catalytic Conversion sensors
d. CNG-4 test set
e. AN/ALQ-151(V) NMHC Probe **5.** ________

6. Ozone pollution control continues to be a problem despite extraordinary improvements in vehicle emissions and cleaner fuel sources because __________.

a. NMHCs are an ozone-depleting compound
b. fewer people use high occupancy vehicle (HOV) lanes or public transportation
c. significant increases in passenger miles offset gains
d. regulatory measures have been relaxed by recent legislation
e. damage to the ozone layer may be irreparable **6.** ________

7. What engine operating factor is most responsible for the emission of CO ?

a. Incomplete fuel combustion
b. Crankcase emissions
c. Evaporative losses
d. Lean air/fuel mixtures
e. High compression ratio **7.** ________

8. The following gases are produced during the combustion cycle, **except** __________.

a. Unburned hydrocarbons (NMHCs)
b. Carbon monoxide
c. Nitrogen oxides
d. Carbon dioxide (CO_2)
e. Lead (Pb) **8.** ________

9. In 1990, mobile source emissions accounted for about __________ of the hazardous air pollutants emitted in urban area of the U.S.

a. 80 percent
b. 50 percent
c. 20 percent
d. 35 percent
e. 75 percent **9.** ________

10. Lead alkalis were added to gasoline in order to __________.

a. avoid the additional cost of refining high-octane fuels
b. significantly improve fuel volatility, anti-knock and carbon deposit-forming tendencies
c. boost octane ratings to enhance ignition and burn rates
d. increase the amount of fuel produced by a given quantity of crude oil
e. produce premium-grade leaded gasoline for significantly less money

10. _______

Matching

Directions: *Match each of the following mobile source control measures with the proper description.*

Control Measures for Vehicle Emissions

_______ **11.** Thermactor system
_______ **12.** Engine modifications
_______ **13.** Lower compression ratios
_______ **14.** Recirculate exhaust gas
_______ **15.** Delayed spark timing
_______ **16.** Alternative fuels
_______ **17.** Dual or three-way catalytic systems

a. A method in which chamber temperatures and NOx Emissions are reduced.

b. A method of changing the ignition process so that ignition occurs in the compression stroke, reducing the temperatures produced and decreasing the production of NOx.

c. A method of reducing NOX emissions by relocating the HC-CO oxidation catalyst downstream from the NOx reduction catalyst.

d. A method of controlling NMHCs and CO in which air is pumped into the exhaust manifold. The air-rich environment permits a more complete combustion of volatile gases.

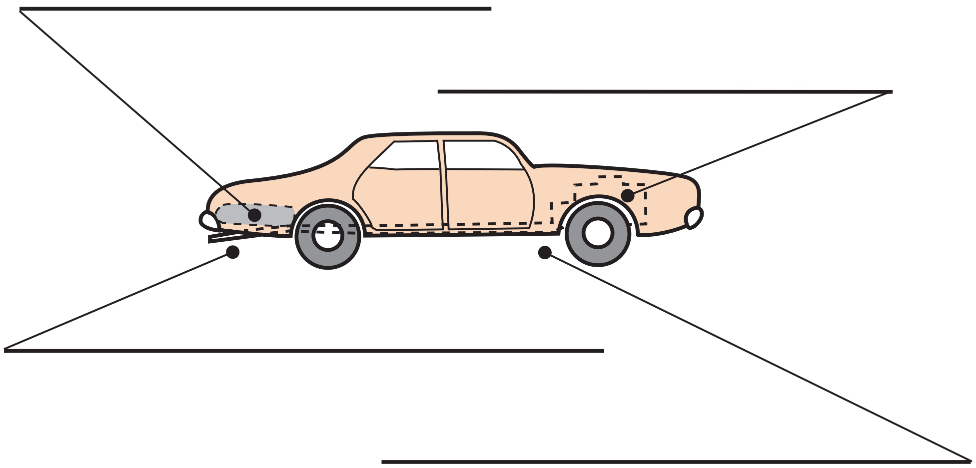
e. Electric cells, oxygenated additives, and compressed or liquefied gases are a few of the means used to to reduce vehicle emissions.

f. Changes in air-fuel mixtures, ignition timing, and catalytic converters are some of the ways to effectively reduce vehicle emissions.

g. The most effective way to reduce NOx emissions is to recirculate controlled amounts of exhaust gas through the intake manifold.

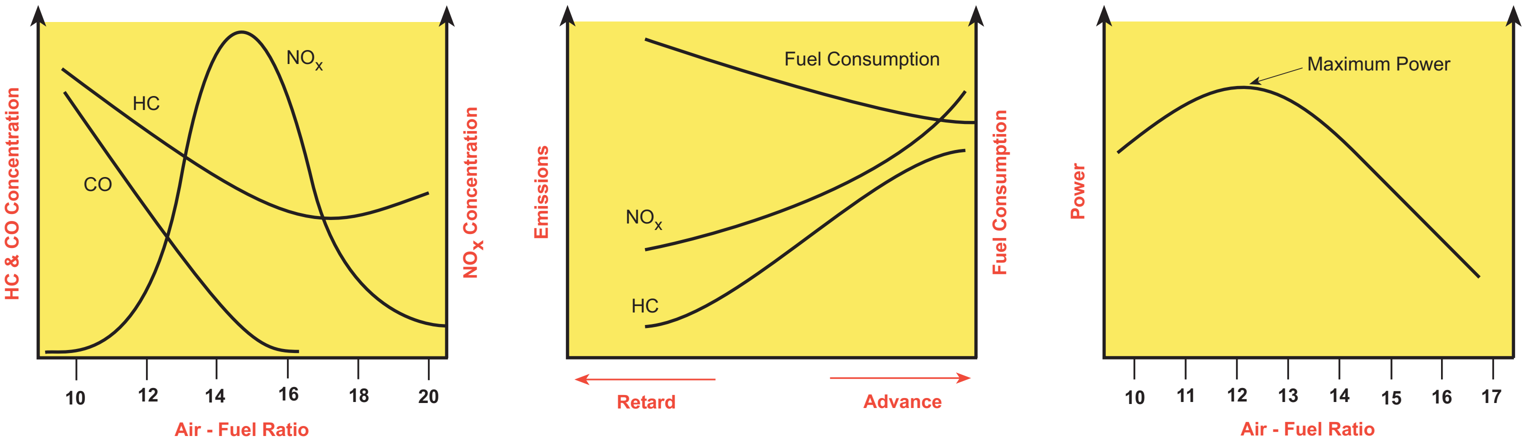
Emissions and Emission Sources

Directions: *In the spaces provided, identify (1) the fugitive emission and (2) the emission source for the following light duty motor vehicle.*



Air – Fuel Ratio Interpretation

Directions: *Review the following data and circle the correct answer to the questions provided.*



(Source: Godish, Thad, *Air Quality*, Lewis: New York, 1997, p. 289, 292, 297.)

18. Nitrogen oxide emissions [**increase** / **decrease**] as fuel consumption rises.

19. Carbon monoxide emissions are at their [**highest** / **lowest**] when air-fuel ratios become lean.

20. Based on the evidence, HC, CO, and NO_X emissions are at their lowest with an air-fuel ratio of ____________; as motor vehicle power is [**increasing** / **decreasing**].

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	A	11-7
2.	C	11-4
3.	E	11-7
4.	D	11-11
5.	B	11-13
6.	C	11-3
7.	A	11-8
8.	E	11-7
9.	B	11-3
10.	D	11-14
11.	D	
12.	F	
13.	A	
14.	G, E	
15.	B	
16.	E	
17.	C	

Diagram- TOP LEFT- Fuel Tank (HC), TOP RIGHT- Carburetor (HC), BOTTOM LEFT- Exhaust (CO, HC, NOx), BOTTOM RIGHT- Crankcase Blowby (HC)

No.	Answer
18.	Decrease
19.	Highest
20.	18 and decreasing

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CHAPTER 12

Pollution Prevention

Lesson Goal

Demonstrate an understanding of the basic principles and methods used in Pollution Prevention (P2) by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Define Pollution Prevention (P2).
2. Describe the control initiatives introduced by Pollution Prevention (P2) professionals.
3. Describe the environmental protection "hierarchy."
4. Discuss pollution prevention strategies currently in use.
5. Discuss the application of Pollution Prevention (P2) principles to air pollution control.
6. Relate the economics of pollution prevention as one of the lowest cost options for waste management.
7. List the tasks and subtasks of a Pollution Prevention Assessment for a facility.
8. Create a flow diagram that accurately depicts the hierarchy of pollution prevention strategies.
9. Explain how plant design and layout can dramatically affect the creation of pollutants.
10. List and explain the legislative landmarks that have significantly influenced Pollution Prevention.

Recommended Reading: Godish, Thad, "Pollution Prevention," *Air Quality*, 3rd Edition, New York: Lewis, 1997, pp. 311-312.

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Pollution Prevention

For decades, research and government regulation have been conducted to focus the attention of the environmental community on the measurement and control of pollutants in the ambient air. However, slowly emerging within the pages of air pollution control is a new approach to waste management: a strategy known as Pollution Prevention. For decades, air pollution professionals have been so consumed with how to *control* and *eliminate* air pollution that little thought was given to *preventing* its creation. Recognizing this deficiency, Congress passed the Clean Air Act Amendment of 1990 and installed the framework and structure for an effective pollution prevention program.

Pollution prevention emphasizes the reduction or elimination of waste production *before* it is emitted into the environment (Theodore and McGuinn, 1992). Scientists, engineers, and technicians joining this new effort of air pollution management focus their attention on how industries can reduce or altogether eliminate the production of waste at the source. At industrial or commercial facilities, pollution prevention may require the substitution of process chemicals in the refining process that will be less hazardous to human health or the environment. Pollution prevention may also include creative alterations of the process, equipment, or plant operating practices in order to reduce or eliminate air pollution. Finally, pollution prevention may include more efficient maintenance procedures in order to reduce pollution or conserve energy at the source.

Pollution prevention emphasizes the reduction or elimination of waste production before it is emitted into the environment.

However, applying pollution prevention strategies such as these offers no guarantee that all production process waste will be eliminated. Instead, these strategies are designed to equip industry with cost-effective tools to combat the production of unnecessary waste and pollution through every phase of the production process. Pollution reduction strategies are only a first step among many to prevent the harmful effects of air pollution to human health and the environment.

Because the air pollution professional must be familiar with pollution prevention and waste management techniques, this chapter offers a pertinent review of the legislative history of this relatively new field and the various strategies that may be employed to reduce waste from the production process.

Legislative History

The Pollution Prevention Act (1990) shifted the focus from the measurement and control of industrial emissions to preventing the generation of pollution altogether.

Since much of the air pollution problem in the United States is plant, process, or vehicle related, Congress and the U.S. EPA drafted a new management strategy directed toward controlling these pollutants. The Pollution Prevention Act (1990) shifted the focus from the measurement and control of industrial emissions to preventing the generation of pollution altogether. While only a fine distinction may appear to exist between the two approaches, the Act clearly defines Pollution Prevention. According to the legislation, Pollution Prevention is any reduction of generated waste or recycling activity undertaken at the pollutant source that results in either (1) a reduction in the *total volume* or *quantity* of waste or (2) a reduction in the *toxicity* of the waste in order to eliminate the threat to human health and the environment.

Resource Conservation and Recovery Act (1984). The concept of pollution prevention first emerged in an amendment to the Resource Conservation and Recovery Act (RCRA) in 1984. Congress made “waste minimization” – as pollution prevention was first defined – a national policy objective and declared that the generation of hazardous waste was to be reduced or eliminated wherever possible. On the heels of the RCRA, Congress issued an important 1986 report (EPA/530-SW-033) that more narrowly defined and articulated the concept of “waste minimization” or pollution prevention (Theodore and Young, 1992). This legislation regulates over 400 various chemicals and compounds that require treatment or disposal.

Superfund Amendments and Reauthorization Act (1986). The of Superfund Amendments and Reauthorization Act (SARA) of 1986 created the Emergency Planning and Community Right-To-Know Act (EPCRA), also known as SARA Title III. This statute was designed to improve community access to information about local chemical hazards and to facilitate development of chemical emergency response plans by State and local agencies. EPCRA requires that companies in specific categories that manufacture, process, or use chemicals in specified quantities must file written reports, provide notification of spills or releases and maintain an inventory of toxic chemicals. Certain companies are required to submit annual reports listing any releases of “toxic chemicals” in relation to EPCRA Section 313, and commonly known as the Toxic Chemical Release Inventory (Form R). A company reports any releases made during the preceding twelve months on Form R. All information submitted pursuant to EPCRA regulations is publicly accessible, unless protected by a trade secret claim. This report allows EPA to compile the national Toxic Release Inventory (TRI) database.

EPCRA also required the establishment of State emergency response commissions (SERCs) responsible for coordinating certain emergency response activities and for appointing local emergency planning committees (LEPCs) (Cheremisinoff, 2001).

Pollution Prevention Act (1990). This landmark legislation was passed in 1990 that established pollution prevention as a national objective. The Pollution Prevention Act (PPA) raised pollution prevention from “a desirable goal” to the status of national policy and created the U.S. EPA’s Office of Pollution Prevention. The law directs every facility to report information about the management of each toxic chemical they release or treat and requires manufacturing facilities to describe what efforts have been made to eliminate or reduce the quantities of those chemicals (i.e., pollution prevention and recycling program).

Under Section 6602(b) of the Pollution Prevention Act of 1990, Congress established a national policy that:

- Pollution should be prevented or reduced at the source whenever feasible.
- Pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible.
- Pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible.
- Disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.

Pollution prevention means “source reduction,” as defined under the Pollution Prevention Act, and other practices that reduce or eliminate the creation of pollutants through:

- increased efficiency in the use of raw materials, energy, water, or other resources.
- protection of natural resources by conservation. [The Pollution Prevention Act defines “source reduction” to mean any practice which reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal.]
- reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants.

This term includes: equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control.

Under the Pollution Prevention Act, recycling, energy recovery, treatment, and disposal are not included within the definition of pollution prevention. Some practices commonly described as “in-process recycling” may qualify as pollution prevention. Recycling that is conducted in an environmentally sound manner shares many of the advantages of prevention—it can reduce the need for treatment or disposal, and conserve energy and resources.

With the passage of PPA, new requirements were added to the Form R Section 6607, which expands and makes mandatory source reduction and recycling information on the EPCRA list of toxic chemicals. The types of information includes: listing of quantities of each listed toxic chemical entering a waste stream with the percentage change from the previous year, quantities of chemicals recycled, source reduction practices, and production changes from the previous year. (Berry and Dennison, 2000)

The provisions of the Act even made continued operation of a plant and its permit reauthorization conditional on improved pollution prevention performance. Local government agencies were empowered with legal and regulatory authority to issue, licenses, or permits and develop codes in order to promote the objectives of pollution prevention. Indeed, the Pollution Prevention Act is one of the most influential pieces of legislation in decades to clearly define and establish strategies for pollution prevention practices and activities (Theodore and Young, 1992).

In February 1991, the EPA instituted a voluntary 33/50 program in which the overall national goal was the 50 percent reduction in the generation of 17 high-priority toxic chemicals by 1995. An interim program goal of 33 percent reduction was set for completion at the end of 1992. The goal was realized in 1995 when 750 million pounds, down from 1.5 billion pounds reported in 1988, was reported for the 17 covered chemicals. The total reduction between 1988 and 1996 was 896 million pounds and a decrease of 60 percent. The program was eliminated in 1996 after having met its goal.

The two most important pieces of legislation that affect federally mandated pollution prevention programs clearly are the RCRA and the Pollution Prevention Act; however, many other regulations also provide legislative guidance to facilities as they design pollution prevention programs. The Clean Air Act (CAA) of 1990 which established MACTs with various P2 provisions under NESHAPs (which originally only regulated six specific pollutants), the Clean Water Act (CWA), which regulates the discharge of 126 priority pollutants into waterways, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Superfund Amendments and Reauthorization Act (SARA), the Hazardous and Solid Waste Amendments (HSWA), the Safe Drinking Water Act (SDWA), the Toxic Substance Control Act (TSCA), Federal Insecticide, the Fungicide and Rodenticide Act (FIFRA), and the Occupational Safety and Health Administration (OSHA) Act, provide the specific details necessary to move each facility from pollution control to pollution prevention (Theodore and Young, 1992).

Pollution Prevention Strategies

Pollution Prevention strategies include source reduction, recycling, waste treatment and disposal.

By the nature of its definition, pollution prevention begins before pollution is created. Therefore, the prevention of pollution is dependent on considerable forethought and planning. In this regard, pollution prevention is much more proactive than traditional control strategies. After every avenue of reducing or eliminating pollutants has been employed, any residual pollutant is recycled into normal plant operations. In the event that remaining waste has no substantial fuel property or recyclable quality, the most effective form of control technology would be to reduce the pollutant toxicity before it is emitted into the ambient air. Disposal by dumping pollution into wells, landfills, or the ocean should be considered only as a last resort.

With regard to air quality, the general strategy of pollution prevention is to reduce the amount of air pollution. This goal is best accomplished through a hierarchy of actions. While each step in the pollution prevention process is an essential act of pollution prevention, their priority and sequence are important. The steps of effective pollution prevention should occur in the following order: source reduction, recycling, waste treatment and disposal.

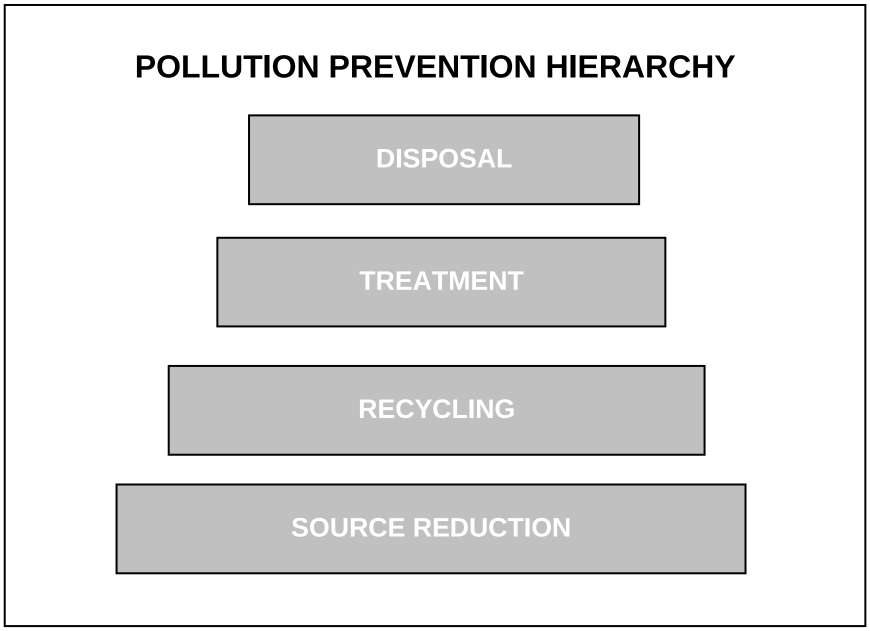


Figure 12-1. Pollution Prevention Hierarchy (Source: Theodore, Louis and McGuinn, Young C., 1992, *Pollution Prevention*, Van Nostrand Reinhold: New York, p. 107.)

Source Reduction. Source reduction is defined as any activity that reduces or eliminates the generation of waste at the source, usually within a production process (Theodore and Young, 1992). Ideally, the opportunity to employ one of the many options of source reduction occurs before a pollutant is even generated. The advantage of reducing or eliminating waste before it occurs is that it altogether avoids the need to later process or dispose of it. Source reduction options can frequently involve only minor procedural changes during processing, rather than the expensive retooling required of control technology solutions. Two of the most useful methods of source reduction are materials substitution and source control.

Source reduction is defined as any activity that reduces or eliminates the generation of waste at the source, usually within a production process.

Material substitution occurs when a fuel source or raw material is replaced by a less toxic or volatile substance that is equally suitable for manufacturing. An effective example of material substitution would be the replacement of chlorofluorocarbons (CFCs) with hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) that are less disruptive to stratospheric ozone. Another good example of material substitution is the process washing of coal and other ores before subjecting them to heat and other manufacturing processes that emit waste. Altering or purifying a raw material in this manner frequently reduces the amount of by-products that must be either reduced or eliminated (Godish, 1997).

A second method of refining pollutant emissions is through source control. Sometimes a change in the equipment or operational settings of a plant can greatly affect the quantity or toxicity of a pollutant. Physically segregating toxic chemicals from one another can also avoid dangerous spills or fugitive emissions produced by chemical mixing. Regardless of which methods may be suitable for a specific industry, changes to plant design and operations or material handling practices can generally be an effective way to reduce the number of catastrophic public health episodes hastened by air pollution (Godish, 1997).

Recycling. Although recycling techniques are also an important means of pollution prevention, they should be used only when other source reduction techniques have been exhausted. On-site recycling of waste is especially effective when a waste product can be used as a fuel supplement or substitute to power a plant's manufacturing operation. Some waste by-products, in fact, have a high enough energy value to serve as a primary fuel source for many industrial operations.

On-site recycling of waste is especially effective when a waste product can be used as a fuel supplement or substitute to power a plant's manufacturing operation.

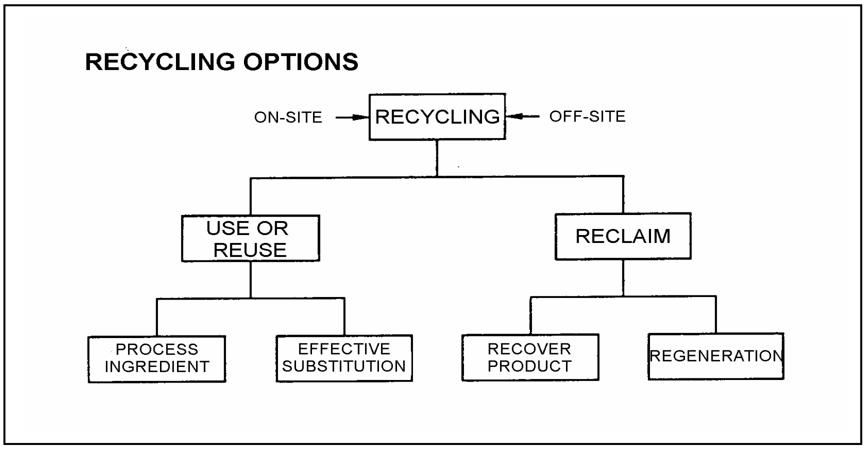


Figure 12-2. Recycling Options (Source: Theodore, Louis and Young C. McGuinn. *Pollution Prevention*. Van Nostrand Reinhold: New York, 1992, p. 107.)

Recycling does not end, however, with on-site reuse. Frequently, waste that has no energy value to one industry can be quite suitable to another. Waste exchange between industries is both economically advantageous and ecologically sound since industry profits from the redistribution of its waste. However, recycling efforts should continue at every step from the factory to the consumer. Certainly more must be done at every level to extend the life of consumed products. Raw materials that are transformed, used, and recycled for different uses not only extend the life and usefulness of the material, but also preserves important resources for future generations (Theodore and Young, 1992).

Treatment. Occasionally, however, a pollutant will have a chemical composition that cannot be reduced, substituted, or effectively recycled. Usually these substances are extremely toxic forms of waste and represent one of the biggest challenges to the pollution prevention specialist. Once chemicals reach this point, they must either be converted to a less toxic form or safely disposed of in secure locations. Waste treatment is often accomplished through chemical or mechanical means and is frequently one of the last options left for safe disposal of pollution.

Treatment of hazardous materials can include incineration, chemical alteration, or biological and physical treatment.

Treatment of hazardous materials can include incineration, chemical alteration, or biological and physical treatment. Technology has provided many means of eliminating such waste, but the most preferable is incineration. Incineration alters the toxic character of a pollutant, and it also disposes of the substance with only minimal residue. The overall goal of any treatment process is to reduce the amount and toxicity of a substance that cannot be eliminated or recycled (Theodore and Young, 1992).

Disposal. Waste disposal can often be the last opportunity to safely shield humans and the environment from the toxic effects of pollution. While disposal is the least attractive of all the options discussed, any substance that cannot be rendered harmless must be disposed of in a safe and responsible manner. The Hazardous and Solid Waste Amendments (1984) detail specific responsibilities of manufacturers or government agencies to properly safeguard the public from hazardous waste disposal. For example, four methods commonly used in hazardous waste

Four methods commonly used in hazardous waste disposal include landfarming, deep-well injection, landfilling, and ocean dumping.

disposal include landfarming, deep-well injection, landfilling, and ocean dumping (Theodore and Young, 1992).

Solid waste can be tilled into soil and used to replenish important nutrients or serve as fertilizer, it can be injected and stored in deep wells, it can be buried in landfills, or it can be placed in storage containers and buried beneath the ocean. Although none of these methods is a particularly attractive solution to waste disposal, they are all a lasting recognition that not every form of waste can be effectively eliminated at the source, recycled, or sufficiently treated. The problems associated with waste disposal should therefore heighten our resolve to discover better ways to prevent pollution.

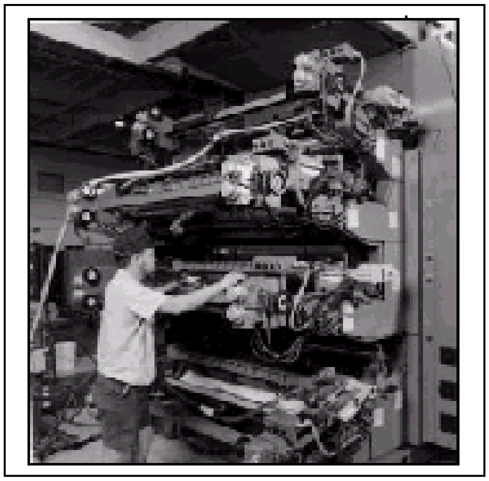
Pollution Prevention Information Clearinghouse

Pollution Prevention Information Clearinghouse (PPIC) is a free, non-regulatory service of the U.S EPA dedicated to reducing or eliminating industrial pollutants through technology transfer, education, and public awareness. PPIC provides access to selected EPA documents, pamphlets, and fact sheets on pollution prevention. The PPIC can also answer questions about pollution prevention or refer you to appropriate contacts for additional. The Pollution Prevention Special Collection, which is located in the OPPTS Chemical Library, includes pollution prevention training materials, conference proceedings, periodicals, and federal and state government publications. The PPIC web site is: http://www.epa.gov/oppt/library/ppicdist.htm.

A Case Study. Facilities' Experiences in Achieving VOC Emissions Reductions: Learning From Three Companies that Reduced VOC Emissions.

This case study presents the steps that three wide web flexographic printers took to reduce their VOC emissions. Their experiences show how to plan a successful reduction of VOC emissions. This case study presents: (1) factors considered in management decisions and how the decisions were implemented and (2) the two methods tried: switching to water-based inks, and installing an oxidizer.

Compliance and Reducing VOC Emissions



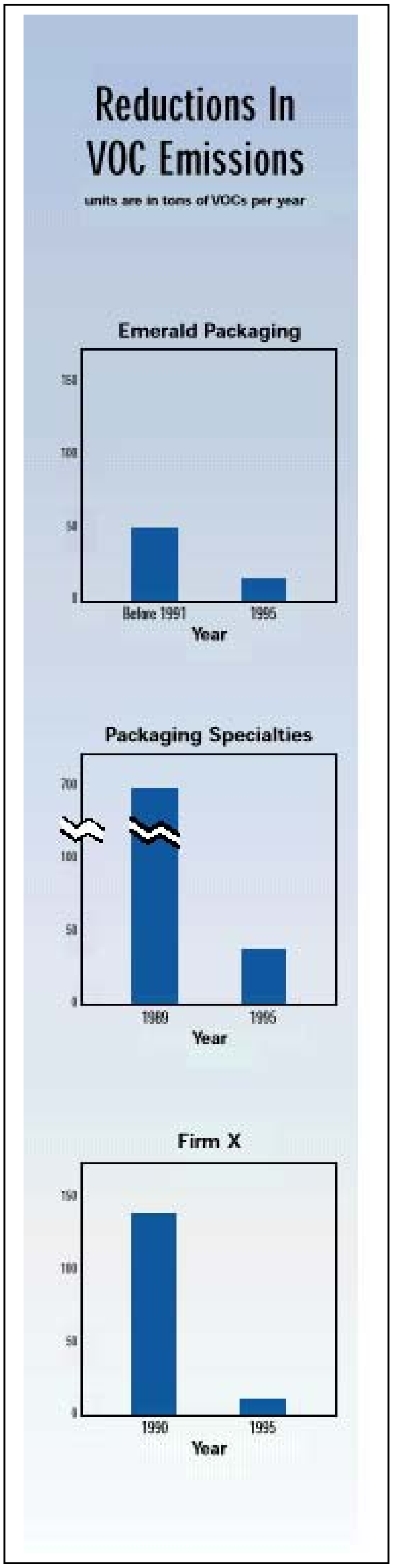
Three printers volunteered to participate in this case study: Emerald Packaging in Union City, California; Packaging Specialties in Fayetteville, Arkansas; and Firm X (this company requested anonymity) in New York. All three flexographers made changes in their ink systems to reduce VOC emissions, primarily to comply with VOC regulations. However, while all three printers shared a similar motivation, the timing of their decisions varied. Emerald Packaging believed that VOC regulations would eventually become more stringent. Even though Emerald Packaging was not faced with immediate regulatory pressure, the company took a proactive approach to reduce VOC emissions. Packaging Specialties, however, faced immediate compliance pressure from the state regulatory agency. The company needed to reduce their VOC emissions in a very short period of time. Like Packaging Specialties, Firm X had to comply with existing regulations within a reasonable time period. However, Firm X was not faced with the same immediate pressure. Each of the three companies considered two options for reducing VOCs:

- Install an oxidizer.
- Replace solvent-based inks with water-based inks.

All three companies decided that the best option for them was to switch to water-based inks, based on several factors. They believed:

- The capital cost of a water-based ink system would be lower than the capital cost of installing an oxidizer.
- Water-based inks would have lower energy costs than an oxidizer.
- In the event of a facility move or expansion, water-based inks would be a more cost-effective choice over the long run.

Emerald Packaging first started using water-based inks in 1988. Working with their ink supplier, the company researched different inks using trial and error. Emerald Packaging converted from solvent-based inks to water-based inks over the course of four years. By 1992, the company used water-based inks on all its presses. When



Emerald was using solvent-based inks and two presses, the company emitted over 50 tons of VOCs a year. Today, using water-based inks on four presses, Emerald emits between 14 and 15 tons of VOCs per year.

Packaging Specialties emitted 702 tons of VOCs in 1989, exceeding permitted levels. The immediate regulatory requirements did not leave Packaging Specialties very much time or flexibility for experimenting with water-based inks. The company switched to water-based inks on all of their flexo presses. However, Packaging Specialties could not develop a water-based ink that would print success-fully on polyvinyl chloride (PVC) or Cryovac, two of the company's primary sub-strates. Customers complained, and up to 5% of all finished products were returned. After 14 months of trying the water-based inks, Packaging Specialties installed an oxidizer and went back to using solvent-based inks. With the oxidizer and 100% room capture, the company reduced annual VOC emissions by approximately 95% and now emits between 35 and 40 tons of VOCs per year. Firm X first attempted to switch to water-based inks in 1990, but the results were disappointing. In 1992, the company tried again. It contacted 14 ink manufacturers to find a suitable water-based ink. Firm X also hired a consultant knowledgeable about printing technology and environmental compliance. Unlike Emerald Packaging and Packaging Specialties, Firm X was not producing packaging. Its substrates required a matte finish, so the company did not have to worry about gloss. With the help of their ink supplier and consultant, Firm X successfully converted from solvent-based inks to water-based inks within nine months. Firm X currently emits less than half of their permitted level of 25 tons of VOCs per year.

Lessons Learned

Plan VOC reductions as soon as possible. Emerald Packaging and Firm X found that planning ahead gave them enough time to successfully phase-in water-based inks. If facilities do not plan ahead, they may not have enough time to research and optimize the process. Such facilities often find the transition to water-based inks difficult or unsuccessful. By taking action to reduce VOCs, companies can make an efficient and successful change. Regardless of what the regulations are, reducing VOCs will always benefit worker health and the environment in the community. These three facilities reduced VOC emissions by switching to water-based inks or installing an oxidizer. Consider options for reducing VOC emissions at a facility. Ultraviolet-cured coating and ink technologies are drawing attention for their low-VOC applications. Other sources of VOCs in the facility, such as cleaning agents should be looked at. Through materials substitution and reduced overall use, these VOCs can be reduced as well.

Use Resources

Ink suppliers. Ink suppliers played an important role in the successful development of water-based inks at Emerald Packaging and Firm X. Initially, the water-based inks at these companies did not dry quickly enough, and the ink density was unsatisfactory. Through close cooperation, both companies and their ink suppliers were able to develop inks that printed successfully. In addition, both Emerald and Firm X modified press equipment and drying systems to improve print quality. Packaging Specialties also worked closely with their ink supplier, but they could not develop a successful water-based ink. In fact, management could not find any ink supplier that had successfully printed water-based inks on PVC or Cryovac.

Trade Associations. Trade associations are valuable resources for printers trying to reduce VOC emissions. The California Film Extruders and Converters Association (CFECA) gave Emerald Packaging information and feedback from other members. The Flexographic Technical Association (FTA) provided Firm X with up-to-date information about different ink technologies.

Experienced Consultants. Experienced consultants are another source of help. A consultant knowledgeable about printing technology and environmental compliance was instrumental in the successful switch to water-based inks at Firm X.

Oxidizer Suppliers. Oxidizer suppliers can also be a valuable resource. When water-based inks didn’t work for Packaging Specialties, an oxidizer supplier helped install a catalytic oxidizer and 100% capture system (USEPA, 1997).

NAME ________________________________ DATE ______________SCORE________

CHAPTER 11 POLLUTION PREVENTION

Multiple Choice

Directions: *Read each question and choose the best answer. Write the letter of your answer in the space provided.*

1. The purpose of pollution prevention is to _______.

a. develop cost effective ways to replace expensive control technology
b. better understand on-site pollution recovery methods and recycling techniques
c. install measures aimed to prevent pollution before it is created
d. provide strategic direction for institutionalizing prevention programs
e. reduce air, water, and solid waste through improved control devices **1.**________

2. An example of pollution prevention techniques would include all of the following, **except** _______.

a. changes in industrial processing
b. Improved add-on control technology
c. additional automation
d. changes to operational settings
e. equipment, piping, or other facility layout and design modifications **2.** ________

3. The cornerstone of facility assessment aimed at reducing high-risk substances is the _______.

a. *Resource Conservation and Recovery Act (RCRA)*
b. *Superfund Amendments and Reauthorization Act (SARA)* Title III, Section 313—Toxic Substances
c. Pollution Prevention Information Clearinghouse (PPIC)
d. 33/50 Program
e. USEPA Toxic Release Inventory (TRI) **3.** ________

4. Which of the following *is* **not** a legislative authority for pollution prevention?

a. CAA
b. OSHA
c. FIFRA
d. SARA
e. LEPC **4.** _______

5. The least desirable pollution prevention strategy is ________.

a. source reduction
b. incineration
c. recycling
d. waste treatment
e. disposal

5. ________

6. The method or equipment best used to dispose of solid waste is ________.

a. anerobic digestion
b. rotary kiln incinerator
c. electrostatic precipitators
d. oxidation
e. wet scrubbers

6. ________

7. Which legislation regulates the release of 126 chemicals into water, including VOCs such as benzene, chloroform, and vinyl chloride?

a. *National Emission Standards for Hazardous Air Pollutants* (NESHAPs)
b. *Clean Water Act*
c. *Resource Conservation and Recovery Act* (RCRA)
d. *Superfund Amendments and Reauthorization Act* (SARA) Title III; Section 313
e. *Superfund Amendments and Reauthorization Act* (SARA) Title III; Section 302

7. ________

8. Which legislation regulates more than 400 discarded commercial chemical products destined for treatment of disposal on land?

a. *National Emission Standards for Hazardous Air Pollutants* (NESHAPs)
b. *Clean Water Act*
c. *Resource Conservation and Recovery Act* (RCRA)
d. *Superfund Amendments and Reauthorization Act* (SARA) Title III; Section 313
e. *Superfund Amendments and Reauthorization Act* (SARA) Title III; Section 302

8. ________

9. Which legislation regulates six specific chemicals (i.e., asbestos, beryllium, mercury, vinyl chloride, benzene, and arsenic) released into the air?

a. *National Emission Standards for Hazardous Air Pollutants* (NESHAPs)
b. *Clean Water Act*
c. *Resource Conservation and Recovery Act* (RCRA)
d. SARA Title III; Section 313
e. SARA Title III; Section 302

9. ______

Matching

Directions: *Match each of the following Pollution Prevention strategies and legislative landmarks with the proper description.*

Control Measures for Vehicle Emissions

_______ **10.** *Clean Air Act* (CAA)

_______ **11.** Disposal

_______ **12.** *Pollution Prevention Act*

_______ **13.** *Resource Conservation and Recovery Act* (RCRA)

_______ **14.** Recycling

_______ **15.** Source Reduction

_______ **16.** Treatment

a. The primary method of Pollution Prevention, employed to reduce pollution at the moment it is generated. Two of the most important ways to accomplish this is through material substitution or source control.

b. A P2 strategy that includes techniques such as landfarming, deep-well objection, landfilling, and ocean dumping.

c. Created the U.S. EPA's Office of Pollution Prevention and required manufacturing facilities to develop pollution prevention and recycling programs.

d. A way to render extremely toxic pollutants harmless by significantly altering their composition and toxicity.

e. The first legislation to raise the issue of Pollution Prevention and define it as a national policy objective.

f. Launched pollution prevention programs designed to control emissions from specific pollutants for specific industries (NESHAPs).

g. The second most important means of accomplishing pollution prevention in which raw materials are transformed to extend their life and usefulness.

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	C	12-4
2.	B	All over
3.	D	12-8
4.	E	12-8
5.	E	12-11
6.	B	12-11
7.	B	12-8
8.	C	12-5
9.	A	12-8
10.	F	All over
11.	B	
12.	C	
13.	E	
14.	G	
15.	A	
16.	D	

CHAPTER 13

Laws & Regulations

Lesson Goal

Demonstrate an understanding of the different types of laws, the constitutional limitations on governmental actions and laws, basic administrative law, and where laws are recorded by successfully completing the review questions at the end of the chapter.

Lesson Objectives

1. Describe the different types of laws.
2. Explain the difference between common law and statutory law.
3. Discuss common law nuisance.
4. Explain government and governmental agencies power to pass laws.
5. Explain the Constitutional limitations on governmental actions.
6. Describe the Federal Register System and how it is used.
7. List the various elements of the *Code of Federal Register* (CFR).

Recommended Reading: Godish, Thad, “Regulation and Public Policy,” *Air* Quality, 3rd Edition, New York: Lewis, 1997, pp. 309-340.

References

Godish, T., “Regulation and Public Policy,” Air *Pollution*, New York: Lewis Publishers, 1997, pp. 238-239.

Kunz, C., Schmedemann, D., Erlinder, C., Downs, M., “*The Process of Legal Research*,” Little, Brown and Company, Boston, 1986.

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U.S. EPA, *Air Pollution Orientation Course*, 1992, pp. 10-15.

Laws and Regulations

The struggle to overcome air pollution continues on many fronts—scientific, technological, and legal. On the legal front, the fight for clean air is being implemented through tougher federal emission standards and a new generation of state and local laws governing air pollution control. Therefore, laws and regulations play an important role in air quality management. Although the development of the science and technology of air pollution control should continue, laws and regulations will remain one of the most important tools that the air pollution professional may use to confront a persistent problem.

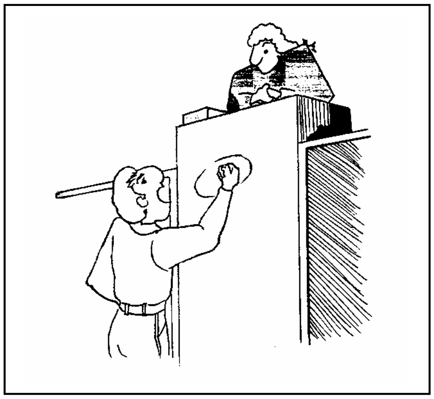
Laws and regulations remain one of the most important tools that an air pollution professional may use to confront the persistent problem of air pollution.

The purpose of this chapter is to review the common law basis of our statutory law, explain rudimentary statutory and administrative law principles, discuss limitations put on governmental activity by the U.S. Constitution, and explain where statutes and regulations can be found.

Common Law

Before air pollution regulations existed, a citizen had little recourse against the spread of air pollution. Since so little was known about the human health and environmental effects of air pollutants, factories and neighbors alike filled the skies with deadly toxins. Historically, a citizen could file suit against another using common law principles and remedies as long as he could prove that a tangible harm had been committed.

An important feature of common law was that a legislative body did not create it as statutory law is



constructed today; rather, common law evolved out of customs and traditions from one circumstance to another, and was enforced by the courts through judicial decisions. It is important to realize that common law is not a fixed or absolute set of written rules in the same sense as statutory laws. As the courts examine each new set of facts in the light of past precedent, an orderly development of common laws develop through a slow and natural process. Some of the common law principles that apply to air pollution control include nuisance and trespass.

Nuisance. Pollution was labeled a nuisance as early as 1611, when an English Court affirmed an injunction and awarded damages to a plaintiff based on a showing that the defendant had erected "a hog sty so near the house of the plaintiff that the air thereof was corrupted."

During the industrial revolution, clean air was not viewed as a health issue, but rather as a property right, which was protected by nuisance provisions in the law.

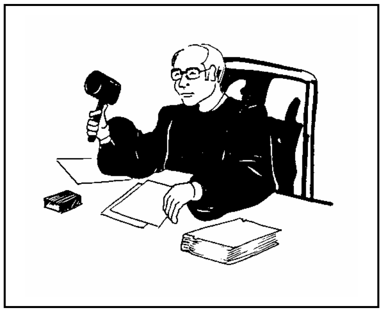
As common law, it was not a personal environmental right to breathe clean air, but rather a property right, which was protected in a nuisance action. During the Industrial Revolution, factories contributed significantly to the vitality and economic wealth of a community. Only in rare instances, when the effects of the pollutant harmed every member of the community, would a justice consider it “an unreasonable interference with the right common to the general public.” Invariably, the property rights of the aristocracy were held in greater esteem than the inconvenience of any single individual. Courts, therefore, seldom granted relief in the form of a permanent injunction against claims of nuisance.

All civil suits fell under the jurisdiction of tort law, or a form of law that permitted a remedy for actual physical harm or damage done to an individual. Under tort law, a claim of nuisance implied that an individual had caused an unreasonable interference with another person’s use of his own property. Nuisance could result from an intentional or negligent act, but the burden of proof was on the injured party to demonstrate to a judge or jury that the act was indeed an “unreasonable” interference. If the injured party prevailed, common law held that they were entitled only to the precise amount of the damage. Since the effects of air pollution on human health and the environment were often difficult to quantify and even more difficult to prove, common law was seldom friendly to an injured party.

Common law nuisance is defined the same as it was over a century ago: a substantial and unreasonable interference with another's use of his property. In testing for the existence of a nuisance, the courts still balance the severity of injury caused by a defendant's conduct verses the defendant's conduct. For example, in allowing an injunction (i.e., shut down or limit defendant's conduct), the court will balance the following factors: defendant's hours of operation, degree of harm caused, who was there first (coming to the nuisance), laches (how long did plaintiff allow the interference before suing), nature of both parties use of their property, conduct of others in the community, the impact of an injunction on people's work, and the availability of a pollution control method.

A nuisance theory can be used effectively in areas where there is no air pollution control standard. For example, in an odor case, the most effective evidence is the testimony of witnesses who can relate how odors from a source make them ill, cause their food to taste funny, keep them awake at night, etc. There are two types of nuisance actions: private and public. A private nuisance harms only the plaintiff. A public nuisance harms the community (i.e., gambling house or obstruction of a highway). Therefore, in our odor case, if only one person complains about the odors, he can file for a private nuisance action in court usually without the help of environmental agencies. If a community complains about the odors, then an environmental agency will usually file for a public nuisance action on behalf of the community.

Trespass. The concept of trespass was another tool in the practice of common law that a citizen might use as a claim for action. Trespass was said to have occurred when a landowner was denied exclusive use of his property. Many argued that particulate-laden smoke that drifted onto a piece of property and caused harm was a violation of the trespass provision of tort law. Generally a plaintiff was more likely to find greater success in making a claim of trespass than nuisance because the standards of "unreasonable interference" and the need to demonstrate actual damage did not apply.



The concept of trespass was another used to combat air pollution. In common law, many argued that particulate-laden smoke deprived landowners of the exclusive use of their property.

Unfortunately, the political and social climate of the newly industrialized British Empire was largely hostile to environmental claims. The argument of trespass, therefore, did no more to solve the larger problem of air pollution than the claims of nuisance (Godish, 1997).

Statutory Law

Today, police power forms the basis of state and local authority to control air pollution. Police allows states to establish laws and regulations to promote the public health, safety, and morals of the community.

In the end, the inability of common law to protect the greater public good was an important reason for the rise of statutory law in America. The American colonists, who had fled the injustice of their English homeland clearly understood the role that wealth and class played in common law proceedings. Rather than forming a government based on the same abuse they had fled, they chose instead to vest legal authority in an elected legislative body that would pass laws to equitably govern public conduct. In concert with the legislative body, the judicial branch was formed to interpret statutory law while the administrative branch was created to enforce it.

Police Power. Police power forms the basis of state and local authority to control air pollution. Simply stated, police power is that power reserved to the states by the U.S. Constitution that allows states to establish laws for the preservation of public order and tranquility; the promotion of the public health, safety, and morals; and, the prevention, detection and punishment of crimes. While states have police power to pass laws, local government can pass laws only if the state delegates them power to pass them (via enabling statutes), or if the local government has been granted home-rule power from their state constitution.

As long as pollution control legislation is founded on the need to protect the public health, not much question can be raised about its constitutional validity. However, some pollution control statutes cover additional areas, such as recreational and aesthetic interests. It is probably safe to say that the strength of a statute's constitutionality decreases as its coverage is extended beyond public health considerations.

Administrative Law

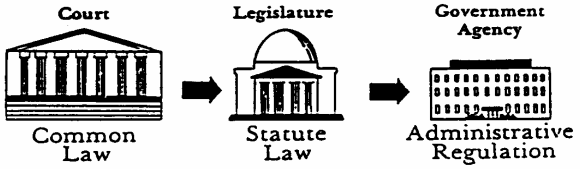
As a practical matter, however, Congress could not foresee every administrative rule or regulation that might be necessary in order to proscribe public behavior. In this regard, agencies such as the U.S. EPA were created with congressional authority to write the rules necessary to properly implement statutory law. An entire body of administrative law was formed, composed of rules and regulations that are often referred to as administrative/regulatory law. Although regulatory law carries with it the full weight and authority of the United States Congress, it is always being challenged, redefined, and adjusted to comply with congressional intent.

Administrative agencies have no inherent or residual authority, but can act (pass laws, etc.) only from authority that is “delegated” to them from state or federal statutes. These statutes are call “enabling” laws or acts. Enabling legislation usually will specify the procedures that an administrative agency must follow. The agency must act in accordance with these procedures. If the enabling legislation is silent on agency procedures, then the agency must follow the procedures outlined in the Administrative Procedure Act (APA). There is a federal APA for federal agencies, and state APAs for state agencies.

Since the 1930s, there has been a trend toward dealing with specialized areas of law by creating administrative agencies to "fill in the details" of a broad statutory framework. This has been done very effectively in the area of air pollution control. Legislators establish agencies, which in turn hire technical personnel and develop expertise to enact rules and regulations in specific areas. Advantages to this approach include:

a. More objectivity and predictability.

b. No harm must be proven when prosecuting for violation of an emission regulation because the legislature has, in effect, declared that any emission exceeding the standard is unlawful.



All administrative law is contained in the Code of Federal Regulations (CFR), while federal regulations are published daily in the Federal Register (FR).

When the different government bodies pass laws, the laws will be statutes, regulations or ordinances, depending on what governmental body passed the law. When legislative bodies pass laws, they are called “statutes” (i.e., federal CAA and state environmental acts). When local governmental units pass laws, they are called “ordinances.” When governmental agencies (state or federal) pass laws, they are called “regulations.” All federal agency regulations are contained in the “Code of Federal Regulations” (CFR). The proposed and final federal regulations are published daily in the “Federal Register.” State agencies follow a similar procedure.

Constitutional Law

The powers of governments and the rights of individuals are defined by the federal and states constitutions. The federal government is a government of limited authority, which may act only through powers that are enumerated in the Constitution. These powers are broadly construed and include the power to pass federal laws that protect public health and welfare.

The rights of individuals are also enumerated in the Constitution, and there is a vast history of judicial interpretation and definition of these constitutional rights. Several amendments to the U.S. Constitution need to be considered by inspectors in the discharge of their duties. These Constitutional protections place a limitation on governmental activity.

Right of Entry: The Fourth Amendment. This Amendment guarantees that citizens (including corporations) will be free from unreasonable search and seizure. It requires that a search warrant be obtained when entry is denied. In order to procure a search warrant, there must be “probable cause” that a violation exists. In *Camara v Municipal Ct. of San Francisco (1967*), the U.S. Supreme Court said that only “reasonable cause” is needed for administrative searches; (this standard requires less proof than is necessary for “probable cause”).

The U.S. Constitution protects individuals from unlawful search and seizure. However, the Supreme Court has ruled that inspectors are not required to obtain a search warrant prior to conducting an investigation of air pollution.

For an inspector, the search and seizure situation arises because most air pollution control statutes have a provision allowing entry into a facility at reasonable hours for the purpose of investigating suspected pollution activities. Usually, inspectors are not required to obtain a search warrant prior to conducting an investigation. The warrantless search is generally justified by the view that air pollution laws are for the protection of public health. If a warrant is not required, the key to the propriety of the search is reasonableness (“reasonable cause”). The search has to be reasonably related to air pollution control purposes and a certain amount of propriety has to be exercised (i.e., the inspection must be conducted during reasonable hours by individuals showing proper identification to the owner or manager of the facility). Therefore, a warrantless search will be justified when there is “reasonable cause” that a violation of a statute (CAA) exists at the facility (i.e., visible emissions or a complaint), or that the plant was inspected as a result of pre-existing scheme or plan for entries (to prevent malevolent motivated inspections).

In *Marshall v. Barlow (1978)*, the U.S Supreme Court held that the Occupational Safety and Health Administration (OSHA) warrantless search statute was unconstitutional. This required OSHA inspectors to obtain warrants prior to entering plant property to determine compliance with OSHA regulations. To date, there has been no such requirement placed on air pollution inspections. This is possibly because the CAA “Right of Entry” Statute (Section 114(a)(2)) allows only limited warrantless administrative searches. Or, since the effects of an air pollution violation are felt directly by the public, the public's right to an investigation of the source seems stronger than in an in-plant situation. In any event, the issue raised by administrative searches involves a

The CAA “Right of Entry” allows limited warrantless administrative searches of private property.

weighing of an individual's right to privacy against the need of a city, state, or Federal program to protect its citizens from hazards to their health or welfare.

Normally, warrants are only sought after entry is refused, because there is no need for a search warrant when the owner or operator has given his consent. If an EPA inspector is refused entry, the standard procedure for EPA is to obtain a search warrant and not even try to use the statutory authority. This avoids constitutional confrontation.

Prohibition Against Self-Incrimination: The Fifth Amendment. This Amendment guarantees that persons cannot be required to give testimony against themselves. This protection applies in criminal cases. If the evidence collected is only used for civil actions such as injunctions or fines, the Fifth Amendment is not applicable. In addition, the Fifth Amendment rights apply only to individuals and not to corporations or partnerships.

Most air pollution control statutes have a provision requiring sources to supply emission inventory and other data to the enforcement agency. The Fifth Amendment has not posed a deterrent to the use of self-reported data when air pollution enforcement actions are civil actions rather than criminal prosecutions. In a case where the evidence or samples taken might be used in a criminal action, the person in authority; at the place where evidence is to be taken should be advised of his rights to remain silent, to have an attorney, and to be made aware that any evidence taken may be used against him in a subsequent criminal action.

The U.S. Constitution also guarantees individuals due process and equal protection under the law. In this regard, people have the right to counsel and the due process against administrative actions.

Due Process: The Fourteenth Amendment. This Amendment guarantees due process of law and equal protection for all citizens. It states that governmental action shall not deprive a person of life, liberty, and property without due process. There are two types of due process: Procedural and Substantive. “Procedural due process” provides people a right to a hearing or other procedures (i.e., notice) before some governmental action is initiated. For example, before an agency passes regulations, one of the best ways of ensuring Procedural due process is to provide an opportunity for public hearing prior to the adoption of regulations or prior to major agency action.

The second type of due process, “Substantive due process,” scrutinizes government action. “Strict scrutiny” is used when governmental action impinges on a fundamental right (i.e., freedom of speech and religion, right of privacy, etc.). “Minimum scrutiny” is used when a lesser right is at stake (i.e., people’s health that is protected by an air pollution statute). The test for “minimum scrutiny” for an environmental law is that the law be applied by the enforcing agency in a *reasonable manner* and that any standard adopted must bear a *reasonable relation* to the interest it is designed to protect (i.e., public health, the quality of air resources, etc.).

Equal Protection: The Fourteenth Amendment. The equal protection clause of the Fourteenth Amendment forbids the enactment of laws that establish *arbitrary* systems of classification or that permits *discrimination* between persons of the same classification. This amendment scrutinizes governmental action the same as due process. The “minimum scrutiny” test for equal protection provides that persons or subjects may be classified for legislative purposes if such classifications are *reasonable* and bear a *rational relationship* to the purpose of the regulation. For example, a VOC control regulation may be directed at hydrocarbon storage tanks of a certain size, while excluding smaller tanks. This would not be unreasonable because the size of a storage tank is related to the amount of evaporative loss and is, therefore, a valid consideration in VOC regulation. However, a regulation would be arbitrary if it provided that any hydrocarbon storage tank with a bumblebee painted on its side would be exempt from regulation. Such a rule would not have any reasonable bearing on air pollution control.

Sources of Federal Statutes

Sources of Federal Law

- *Slip Law*
- *Statutes at Large*
- *United States Code (U.S.C.)*

Slip Laws. The version of a statute published immediately after enactment is called a "slip law" and contains only the text of the new statute. The President signs the slip law with marginal notes added. Slip laws are identified by their public law number, which is assigned after the statute has completed the legislative process. The public law number is not the same as the bill number, which identifies the proposed law during the legislative process.

Statutes at Large. At the close of each congressional session, the federal slip laws are compiled chronologically and published in "*Statutes at Large*." This is a U.S. government publication and is usually published several years after the close of the congressional session to which it refers. It contains every act that was passed during a congressional session, including private laws (laws directed at individuals or specific matters), and is listed by their public law number.

United States Code (U.S.C.). Federal statutes are categorized by topic and are added to the "*United States Code*." The U.S.C. is a collection of statutory provisions organized by subject matter, and is printed by the U.S. Government Printing Office. The U.S.C. is republished every six years and is updated annually with cumulative supplements.

The U.S.C. is divided into 50 "titles." These titles are listed in the front of each U.S.C. volume. Each title is further divided into chapters and subchapters. For example, to find statutes concerning air pollution, you have to go the Title Index and stop at Title 42 "The Public Health and Welfare." Next, locate the Table of Titles and Chapters Index for Title 42 and peruse down the chapter listings until you find "Air Pollution Control" under Chapter 15B. Now that you have title and chapter number, you can locate the volume containing Title 42 and go to the outline containing Chapter 15B to get a list of air pollution statutes including the Clean Air Act.

Sources of Federal Regulations

Sources of Federal Regulation

- *Code of Federal Regulation (CFR)*
- *Federal Register (FC)*

Federal Register. The Federal Register Act of 1935 established a uniform system, called the "*Federal Register*" to handle agency regulations that require filing, public inspection, publication, and codification. The *Federal Register* also serves as a medium to notify the public of official, governmental action, and to publish all documents in chronological order. The *Federal Register* is issued in pamphlet form and is published every weekday except holidays. The FR contains Presidential proclamations, executive orders, and most importantly, agency rules, proposed rules and notices.

Proposed rules first must receive a public hearing and undergo a period of public comment before becoming a final rule. Both the proposed rule, notice for public hearing, and final rule are published in the F*ederal Register*. The final text of a rule will have legal effect on the date indicated in the *Federal Register*, and will be published in the *Code of Federal Regulations* on its next printing. The *Federal Register* will usually be cited as follows: Volume FR Page (Date).

Code of Federal Regulations (C.F.R.). The C.F.R. is an official codification of all currently effective federal regulations. It is updated annually and organized by subject matter, each which is given a "title" number. The C.F.R. is organized by subject matter, while the *Federal Register* is organized chronologically. The C.F.R. is organized into title, chapter, subchapter, part, and section. There are fifty titles areas subject to federal regulation with Title 40 being Protection of the Environment. The chapters are numbered in Roman numerals and are assigned to the single issuing agency (i.e., Chapter 1 is U.S. EPA). Subchapters are lettered in capitals to group related parts (i.e., Subchapter C is Air Programs).

Parts are numbered in Arabic and are the regulations that apply to a single function, agency, or specific subject matter under agency control (i.e., Part 50 is the National Primary and Secondary Ambient Air Quality Standards). The section is the basic unit of the C.F.R., which ideally consists of a short, simple presentation of one proposition. The section number includes the part and paragraph number when internal division of the section is necessary. The C.F.R. will usually be cited as follows: Title CFR Part. Section (year). Thus, 40 CFR 50.1 (2001) refers to Title 40, Part 50, Section 1 in the 2001 year edition.

NAME ______________________________________ DATE _______________SCORE_________

CHAPTER 13 LAWS AND REGULATIONS

Multiple Choice

Directions: Read each question and choose the best answer. Write the letter of your answer in the space provided.

1. Which of the following types of law puts restraints on government actions?

a. Common law
b. municipal law
c. constitutional law
d. state law
e. administrative law **1.**________

2. Activity that is controlled through governmental agencies and which delegates authority through enabling legislation is _______.

a. Common law
b. municipal law
c. constitutional law
d. state law
e. administrative law **2.** ________

3. An important feature of Common law is that it is _______.

a. not enacted by a legislature.
b. written law issued from an officially recognized source.
c. usually more detailed and protective of individual rights than constitutional law.
d. a body of laws and procedures drawn from technical expertise, knowledge, and daily work requirements.
e. unwritten law that emphasizes the separation of government power. **3.** ________

4. The daily *Federal Register* contains _______.

a. Congressional resolutions
b. Common law citations
c. presidential documents
d. State administrative laws and procedures
e. codified judicial rulings **4**. _______

5. In the following federal citation, 40 CFR 50.8, the number ‘50’ represents the _______.

a. Title
b. Chapter
c. Subchapter
d. Part
e. Section

5. _______

6. Under Common law, a claim of _______ implied an unreasonable interference with a person’s use of his property.

a. nuisance
b. trespass
c. reprise
d. attainder
e. tort

6. _______

7. The Common law principle of _______ applied when a landowner was denied exclusive use of his property.

a. nuisance
b. trespass
c. reprise
d. negligence
e. tort

7. _______

8. The 4th Amendment limits which of the following governmental activities?

a. public hearings
b. notice
c. entry of a facility
d. self-incrimination
e. equal protection of the laws

8. _______

9. The 14th Amendment does **not** contain which of the following doctrines?

a. Equal Protection
b. Procedural Due Process
c. Self-incrimination
d. Substantive Due Process
e. none of the above

9. _______

10. Laws passed by a federal or state agency are called_______.

a. regulations
b. statutes
c. ordinances
d. none of the above
e. any of the above

10. _______

Matching

Directions: Match each of the following legal terms with the proper description.

Legal Terminology

_______ **11.** Common Law
_______ **12.** Constitutional Law
_______ **13.** State Law
_______ **14.** Administrative Law
_______ **15.** Slip Law
_______ **16.** Code of Federal Regulations
_______ **17.** Federal Register Act (1935)

a. Passes rules and regulations and is governed by Its enabling act.

b. Established the right of a person to use property as deemed necessary.

c. A uniform system of handling agency regulations that require filing, public inspection, publication, and codification.

d. List the rights of its citizens and puts limitations on Governmental actions.

e. An official codification of the various rules and regulations that govern administrative agencies of the government.

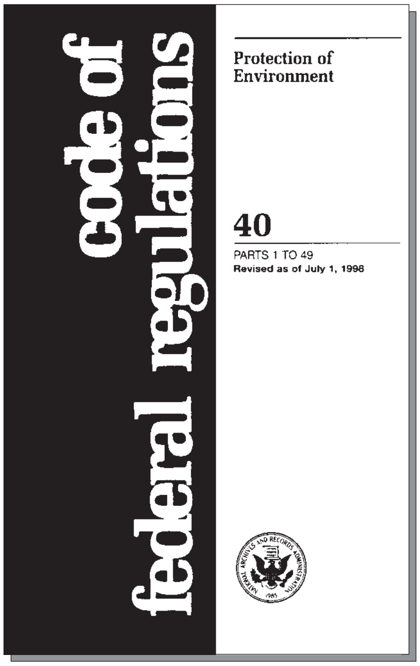
f. A form of law that is generally more protective of Individual rights and is composed of specific laws and enabling acts.

g. A type of law that is passed by Congress and published as a chronological record of a session of Congress.

Code of Federal Regulations

Directions: Review the following information and complete the research questions in the space provided.

The *Code of Federal Regulations (CFR)* is an annually revised codification of the general and permanent rules as published in the *Federal Register* by the executive departments and agencies of the United States Government. The following exercise provides a step-by-step explanation of how to use the Code of Federal Regulations.



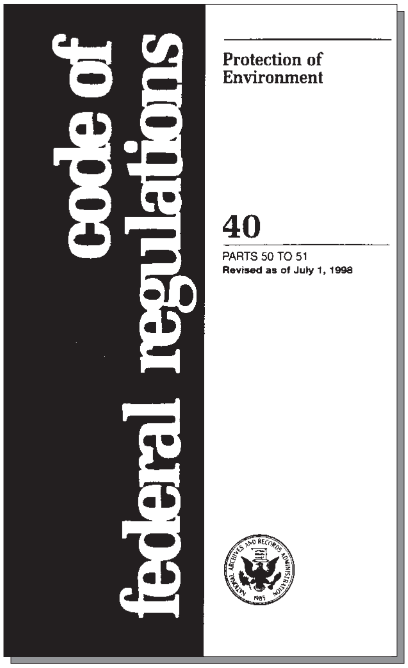
code of federal regulations

Protection of Environment

40

PARTS 1 TO 49

Revised as of July 1, 1998



code of federal regulations

Protection of Environment

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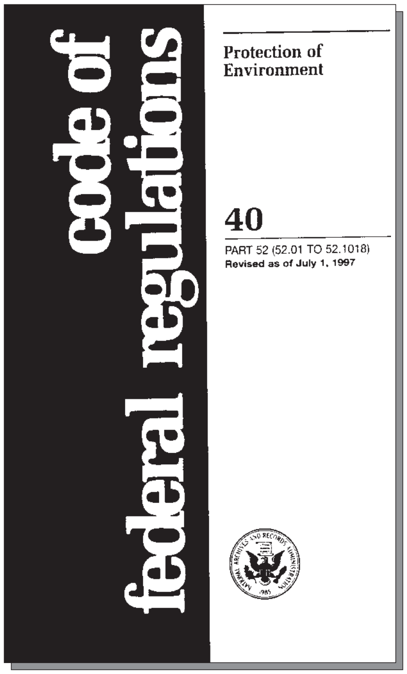
PARTS 50 TO 51

Revised as of July 1, 1998



code of federal regulations

Protection of Environment

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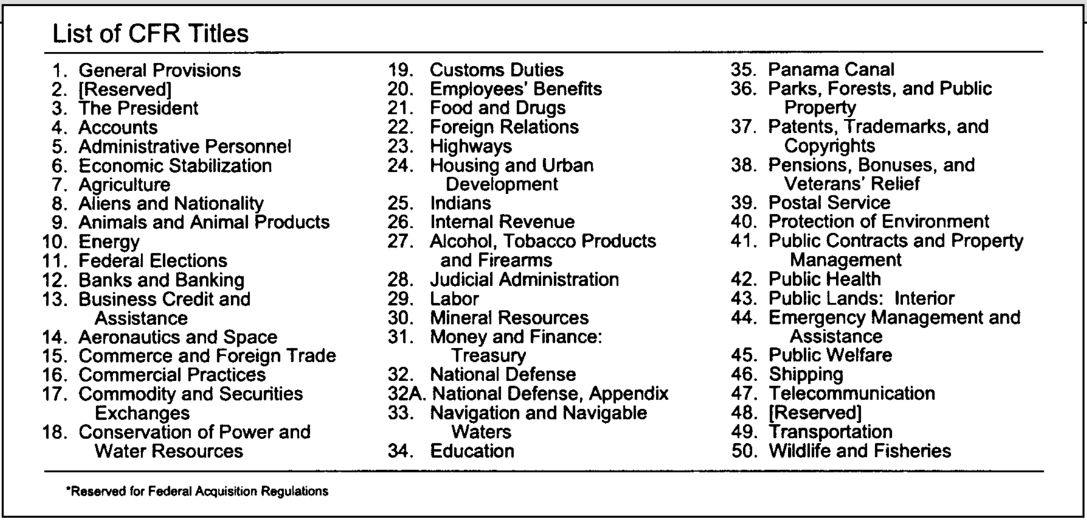
PART 52 (52.01 TO 52.1018)

Revised as of July 1, 1997

Step 1: CFR Title List

Consult the list of CFR Titles and select the one that most directly applies to the specific governmental agency or area of required research. The full text of the *CFR* contains amendments published in the *Federal Register* since the last revision.



List of CFR Titles

1. General Provisions
2. [Reserved]
3. The President
4. Accounts
5. Administrative Personnel
6. Economic Stabilization
7. Agriculture
8. Aliens and Nationality
9. Animals and Animal Products
10. Energy
11. Federal Elections
12. Banks and Banking
13. Business Credit and Assistance
14. Aeronautics and Space
15. Commerce and Foreign Trade
16. Commercial Practices
17. Commodity and Securities Exchanges
18. Conservation of Power and Water Resources
19. Customs Duties
20. Employees' Benefits
21. Food and Drugs
22. Foreign Relations
23. Highways
24. Housing and Urban Development
25. Indians
26. Internal Revenue
27. Alcohol, Tobacco Products and Firearms
28. Judicial Administration
29. Labor
30. Mineral Resources
31. Money and Finance: Treasury
32. National Defense

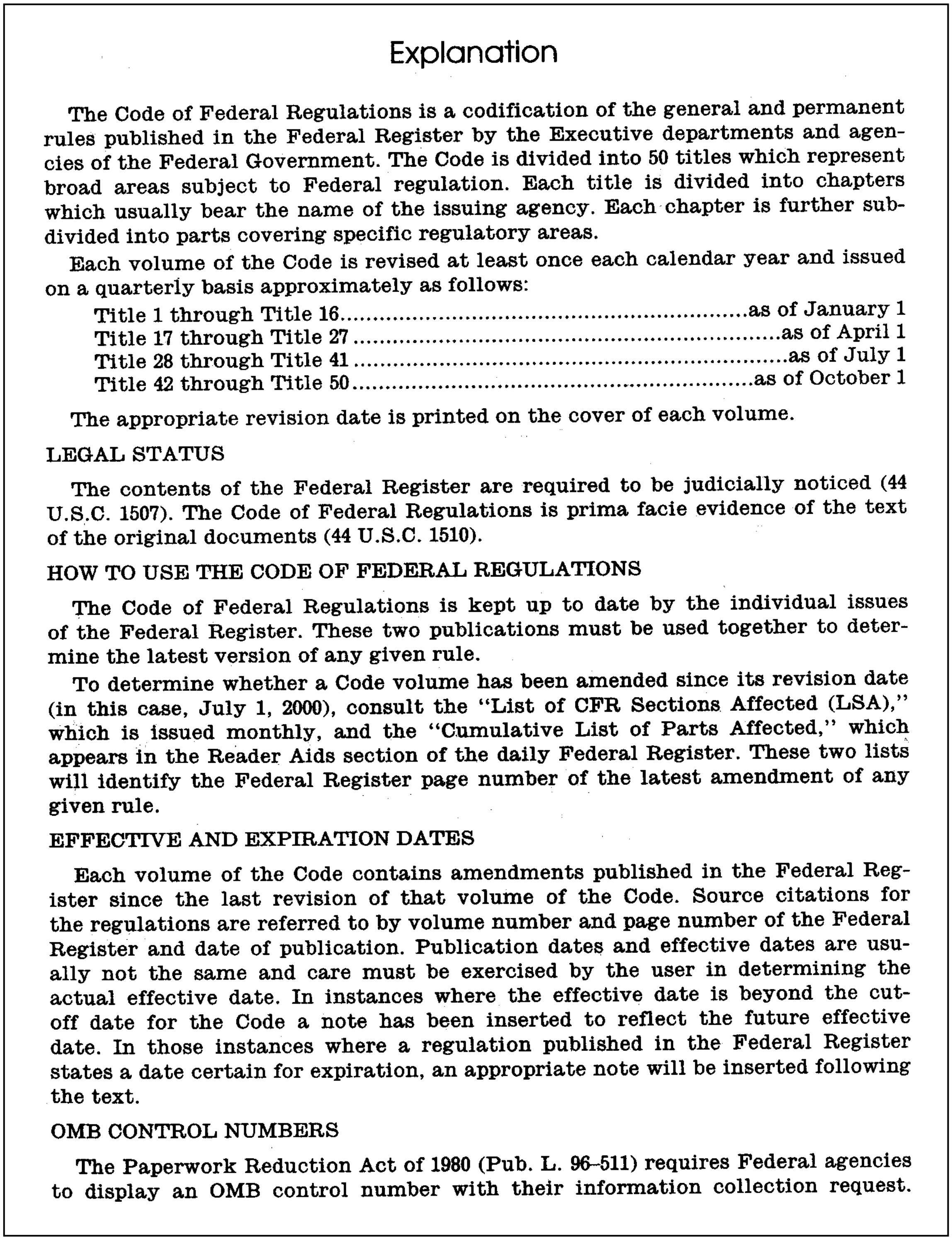
32A. National Defense, Appendix

33. Navigation and Navigable Waters
34. Education
35. Panama Canal
36. Parks, Forests, and Public Property
37. Patents, Trademarks, and Copyrights
38. Pensions, Bonuses, and Veterans' Relief
39. Postal Service
40. Protection of Environment
41. Public Contracts and Property Management
42. Public Health
43. Public Lands: Interior
44. Emergency Management and Assistance
45. Public Welfare
46. Shipping
47. Telecommunication
48. [Reserved]
49. Transportation
50. Wildlife and Fisheries

*Reserved for Federal Acquisition Regulations

Step 2: CFR Explanation

An explanation of the *Code* is displayed in the front of each volume. Of particular importance is a paragraph entitled "How to Use the Code of Federal Regulations." Each volume of the *CFR* is revised at least once each calendar year and issued on a quarterly basis as indicated below. The appropriate revision date is clearly printed on the front cover of each volume and the color of the cover changes with each new revision for easy reference.



Explanation

The Code of Federal Regulations is a codification of the general and permanent rules published in the Federal Register by the Executive departments and agencies of the Federal Government. The Code is divided into 50 titles which represent broad areas subject to Federal regulation. Each title is divided into chapters which usually bear the name of the issuing agency. Each chapter is further subdivided into parts covering specific regulatory areas.

Each volume of the Code is revised at least once each calendar year and issued on a quarterly basis approximately as follows:

Title 1 through Title 16	as of January 1
Title 17 through Title 27	as of April 1
Title 28 through Title 41	as of July 1
Title 42 through Title 50	as of October 1

The appropriate revision date is printed on the cover of each volume.

LEGAL STATUS

The contents of the Federal Register are required to be judicially noticed (44 U.S.C. 1507). The Code of Federal Regulations is prima facie evidence of the text of the original documents (44 U.S.C. 1510).

HOW TO USE THE CODE OF FEDERAL REGULATIONS

The Code of Federal Regulations is kept up to date by the individual issues of the Federal Register. These two publications must be used together to determine the latest version of any given rule.

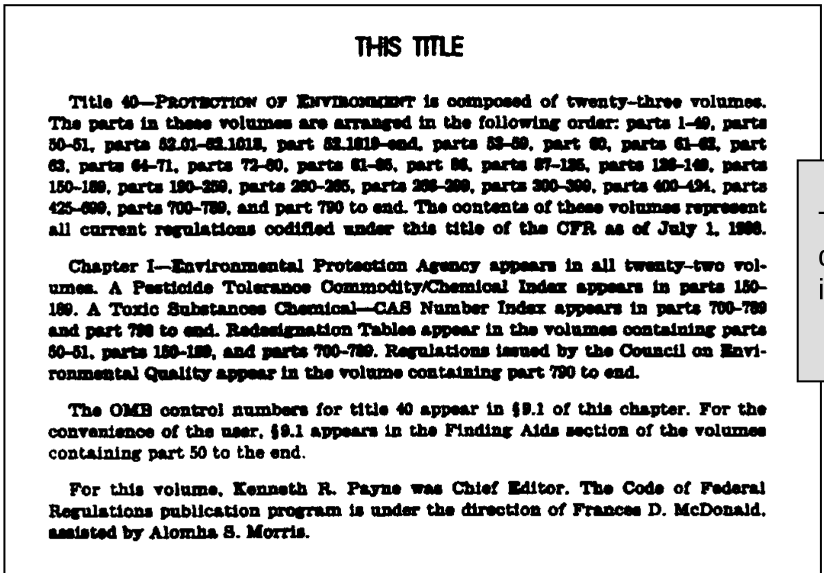
To determine whether a Code volume has been amended since its revision date (in this case, July 1, 2000), consult the "List of CFR Sections Affected (LSA)," which is issued monthly, and the "Cumulative List of Parts Affected," which appears in the Reader Aids section of the daily Federal Register. These two lists will identify the Federal Register page number of the latest amendment of any given rule.

EFFECTIVE AND EXPIRATION DATES

Each volume of the Code contains amendments published in the Federal Register since the last revision of that volume of the Code. Source citations for the regulations are referred to by volume number and page number of the Federal Register and date of publication. Publication dates and effective dates are usually not the same and care must be exercised by the user in determining the actual effective date. In instances where the effective date is beyond the cutoff date for the Code a note has been inserted to reflect the future effective date. In those instances where a regulation published in the Federal Register states a date certain for expiration, an appropriate note will be inserted following the text.

OMB CONTROL NUMBERS

The Paperwork Reduction Act of 1980 (Pub. L. 96–511) requires Federal agencies to display an OMB control number with their information collection request.



THIS TITLE

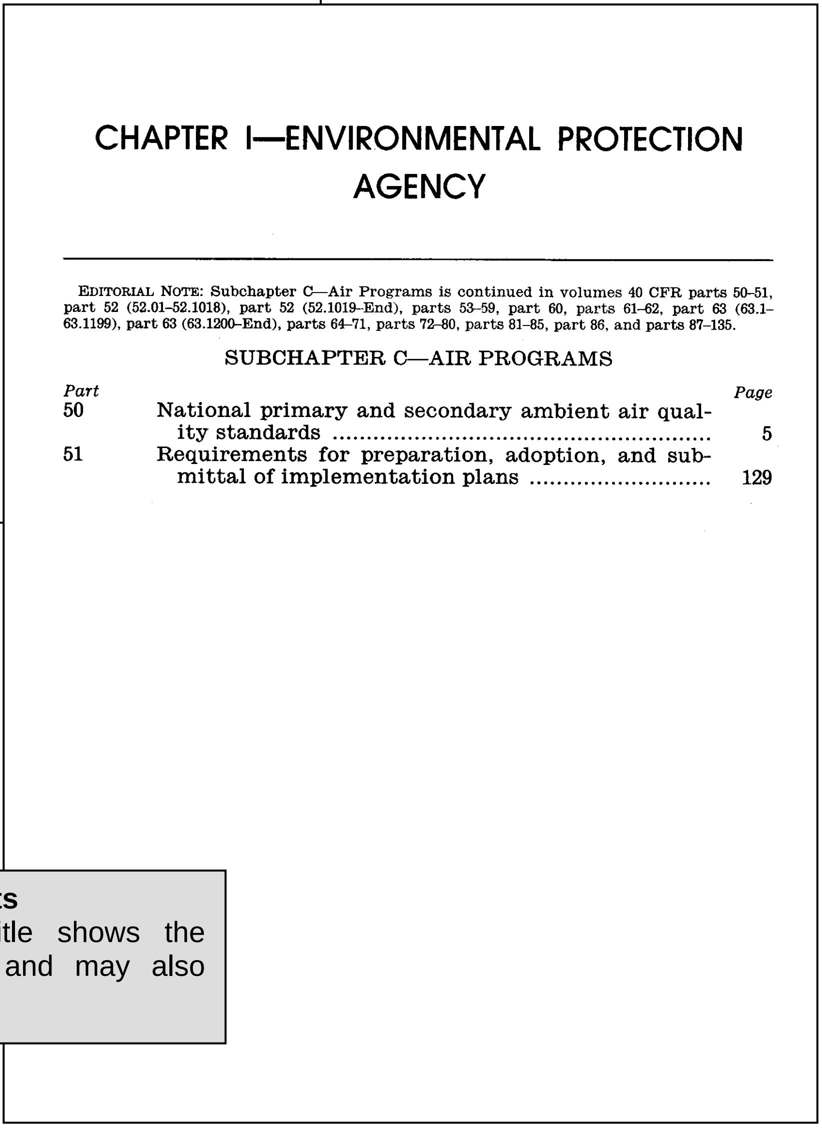
Title 40—PROTECTION OF ENVIRONMENT is composed of twenty-three volumes. The parts in these volumes are arranged in the following order: parts 1–49, parts 50–51, parts 52.01–52.1018, part 52.1019–end, parts 53–59, part 60, parts 61–62, part 63, parts 64–71, parts 72–80, parts 81–85, part 86, parts 87–135, parts 136–149, parts 150–189, parts 190–259, parts 260–265, parts 266–299, parts 300–399, parts 400–424, parts 425–699, parts 700–789, and part 790 to end. The contents of these volumes represent all current regulations codified under this title of the CFR as of July 1, 1998.

Chapter I—Environmental Protection Agency appears in all twenty-two volumes. A Pesticide Tolerance Commodity/Chemical Index appears in parts 150–189. A Toxic Substances Chemical—CAS Number Index appears in parts 700–789 and part 790 to end. Redesignation Tables appear in the volumes containing parts 50–51, parts 150–189, and parts 700–789. Regulations issued by the Council on Environmental Quality appear in the volume containing part 790 to end.

The OMB control numbers for title 40 appear in §9.1 of this chapter. For the convenience of the user, §9.1 appears in the Finding Aids section of the volumes containing part 50 to the end.

For this volume, Kenneth R. Payne was Chief Editor. The Code of Federal Regulations publication program is under the direction of Frances D. McDonald, assisted by Alomha S. Morris.

Step 3: Title Explanation
The Title explanation contains a brief description of each volume as well as important bibliographic information.



CHAPTER I—ENVIRONMENTAL PROTECTION AGENCY

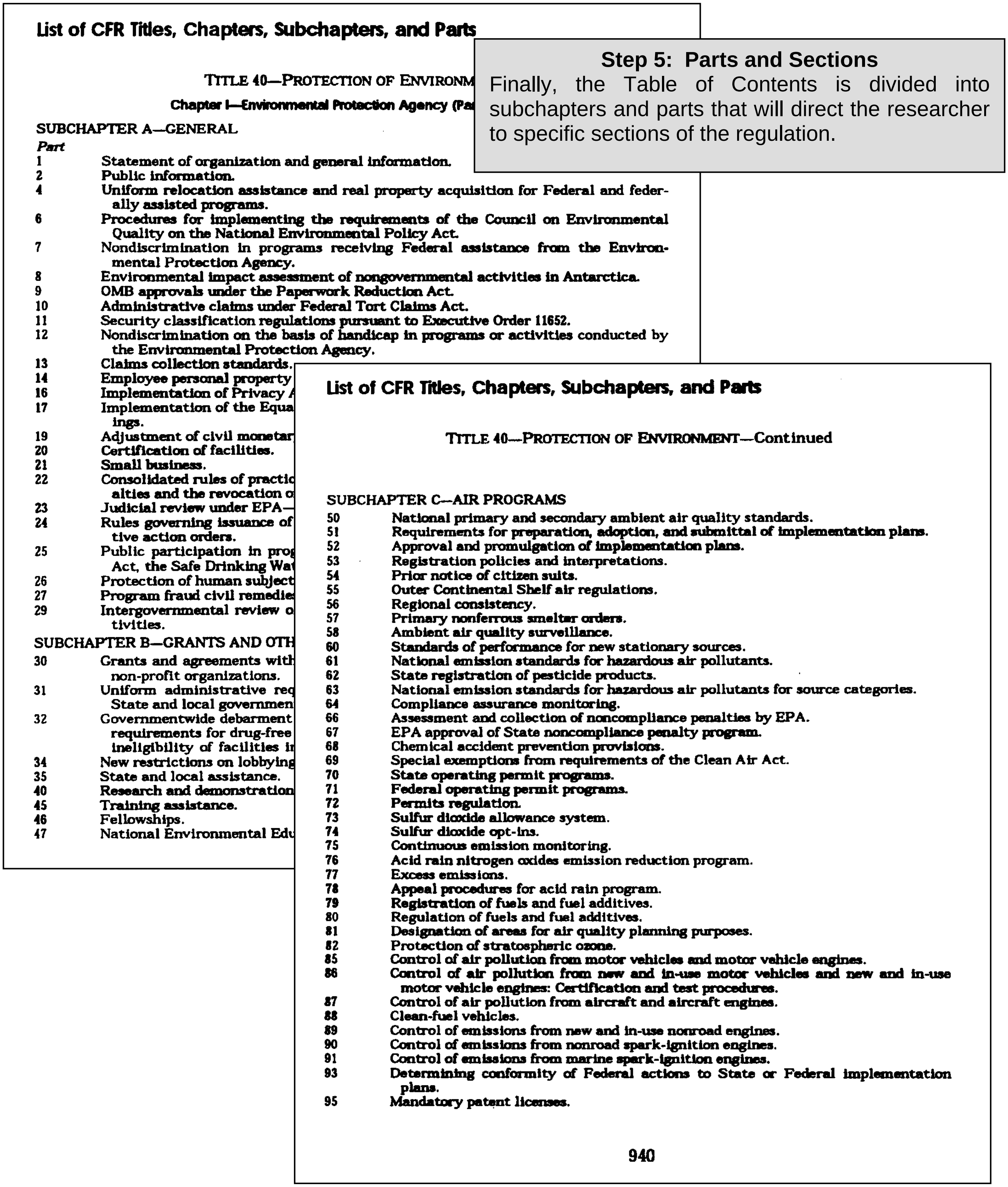
EDITORIAL NOTE: Subchapter C—Air Programs is continued in volumes 40 CFR parts 50–51, part 52 (52.01–52.1018), part 52 (52.1019–End), parts 53–59, part 60, parts 61–62, part 63 (63.1–63.1199), part 63 (63.1200–End), parts 64–71, parts 72–80, parts 81–85, part 86, and parts 87–135.

SUBCHAPTER C—AIR PROGRAMS

Step 4: Table of Contents
The Table of Contents for each Title shows the assignment of chapters to agencies and may also include cross-reference information.

Step 5: Parts and Sections

Finally, the Table of Contents is divided into subchapters and parts that will direct the researcher to specific sections of the regulation.



List of CFR Titles, Chapters, Subchapters, and Parts

TITLE 40—PROTECTION OF ENVIRONM

Chapter I—Environmental Protection Agency (Pa

SUBCHAPTER A—GENERAL

Part	
1	Statement of organization and general information.
2	Public information.
4	Uniform relocation assistance and real property acquisition for Federal and federally assisted programs.
6	Procedures for implementing the requirements of the Council on Environmental Quality on the National Environmental Policy Act.
7	Nondiscrimination in programs receiving Federal assistance from the Environmental Protection Agency.
8	Environmental impact assessment of nongovernmental activities in Antarctica.
9	OMB approvals under the Paperwork Reduction Act.
10	Administrative claims under Federal Tort Claims Act.
11	Security classification regulations pursuant to Executive Order 11652.
12	Nondiscrimination on the basis of handicap in programs or activities conducted by the Environmental Protection Agency.
13	Claims collection standards.
14	Employee personal property
16	Implementation of Privacy A
17	Implementation of the Equa ings.
19	Adjustment of civil monetar
20	Certification of facilities.
21	Small business.
22	Consolidated rules of practic alties and the revocation o
23	Judicial review under EPA—
24	Rules governing issuance of tive action orders.
25	Public participation in prog Act, the Safe Drinking Wat
26	Protection of human subject
27	Program fraud civil remedie
29	Intergovernmental review o tivities.

SUBCHAPTER B—GRANTS AND OTH

30	Grants and agreements with non-profit organizations.
31	Uniform administrative req State and local governmen
32	Governmentwide debarment requirements for drug-free ineligibility of facilities in
34	New restrictions on lobbying
35	State and local assistance.
40	Research and demonstration
45	Training assistance.
46	Fellowships.
47	National Environmental Edu

List of CFR Titles, Chapters, Subchapters, and Parts

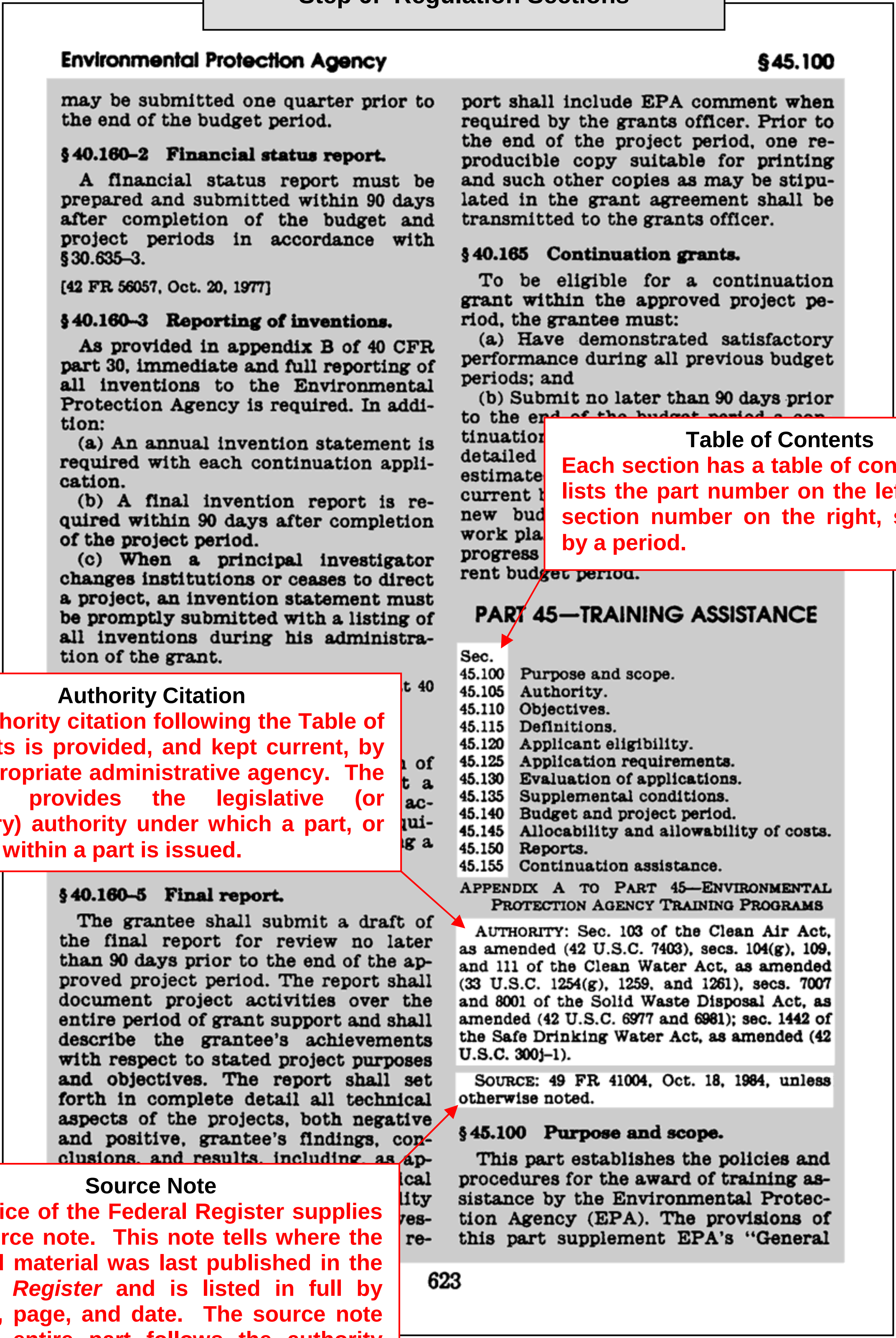
TITLE 40—PROTECTION OF ENVIRONMENT—Continued

SUBCHAPTER C—AIR PROGRAMS

50	National primary and secondary ambient air quality standards.
51	Requirements for preparation, adoption, and submittal of implementation plans.
52	Approval and promulgation of implementation plans.
53	Registration policies and interpretations.
54	Prior notice of citizen suits.
55	Outer Continental Shelf air regulations.
56	Regional consistency.
57	Primary nonferrous smelter orders.
58	Ambient air quality surveillance.
60	Standards of performance for new stationary sources.
61	National emission standards for hazardous air pollutants.
62	State registration of pesticide products.
63	National emission standards for hazardous air pollutants for source categories.
64	Compliance assurance monitoring.
66	Assessment and collection of noncompliance penalties by EPA.
67	EPA approval of State noncompliance penalty program.
68	Chemical accident prevention provisions.
69	Special exemptions from requirements of the Clean Air Act.
70	State operating permit programs.
71	Federal operating permit programs.
72	Permits regulation.
73	Sulfur dioxide allowance system.
74	Sulfur dioxide opt-ins.
75	Continuous emission monitoring.
76	Acid rain nitrogen oxides emission reduction program.
77	Excess emissions.
78	Appeal procedures for acid rain program.
79	Registration of fuels and fuel additives.
80	Regulation of fuels and fuel additives.
81	Designation of areas for air quality planning purposes.
82	Protection of stratospheric ozone.
85	Control of air pollution from motor vehicles and motor vehicle engines.
86	Control of air pollution from new and in-use motor vehicles and new and in-use motor vehicle engines: Certification and test procedures.
87	Control of air pollution from aircraft and aircraft engines.
88	Clean-fuel vehicles.
89	Control of emissions from new and in-use nonroad engines.
90	Control of emissions from nonroad spark-ignition engines.
91	Control of emissions from marine spark-ignition engines.
93	Determining conformity of Federal actions to State or Federal implementation plans.
95	Mandatory patent licenses.

940

Step 6: Regulation Sections



Environmental Protection Agency **§45.100**

may be submitted one quarter prior to the end of the budget period.

§40.160–2 Financial status report.

A financial status report must be prepared and submitted within 90 days after completion of the budget and project periods in accordance with §30.635–3.

[42 FR 56057, Oct. 20, 1977]

§40.160–3 Reporting of inventions.

As provided in appendix B of 40 CFR part 30, immediate and full reporting of all inventions to the Environmental Protection Agency is required. In addition:

(a) An annual invention statement is required with each continuation application.

(b) A final invention report is required within 90 days after completion of the project period.

(c) When a principal investigator changes institutions or ceases to direct a project, an invention statement must be promptly submitted with a listing of all inventions during his administration of the grant.

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§40.160–5 Final report.

The grantee shall submit a draft of the final report for review no later than 90 days prior to the end of the approved project period. The report shall document project activities over the entire period of grant support and shall describe the grantee's achievements with respect to stated project purposes and objectives. The report shall set forth in complete detail all technical aspects of the projects, both negative and positive, grantee's findings, conclusions, and results, including as ap-
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port shall include EPA comment when required by the grants officer. Prior to the end of the project period, one reproducible copy suitable for printing and such other copies as may be stipulated in the grant agreement shall be transmitted to the grants officer.

§40.165 Continuation grants.

To be eligible for a continuation grant within the approved project period, the grantee must:

(a) Have demonstrated satisfactory performance during all previous budget periods; and

(b) Submit no later than 90 days prior to the en
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detailed
estimate
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rent budget period.

PART 45—TRAINING ASSISTANCE

Sec.

AUTHORITY: Sec. 103 of the Clean Air Act, as amended (42 U.S.C. 7403), secs. 104(g), 109, and 111 of the Clean Water Act, as amended (33 U.S.C. 1254(g), 1259, and 1261), secs. 7007 and 8001 of the Solid Waste Disposal Act, as amended (42 U.S.C. 6977 and 6981); sec. 1442 of the Safe Drinking Water Act, as amended (42 U.S.C. 300j–1).

SOURCE: 49 FR 41004, Oct. 18, 1984, unless otherwise noted.

§45.100 Purpose and scope.

This part establishes the policies and procedures for the award of training assistance by the Environmental Protection Agency (EPA). The provisions of this part supplement EPA's "General

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Table of Contents

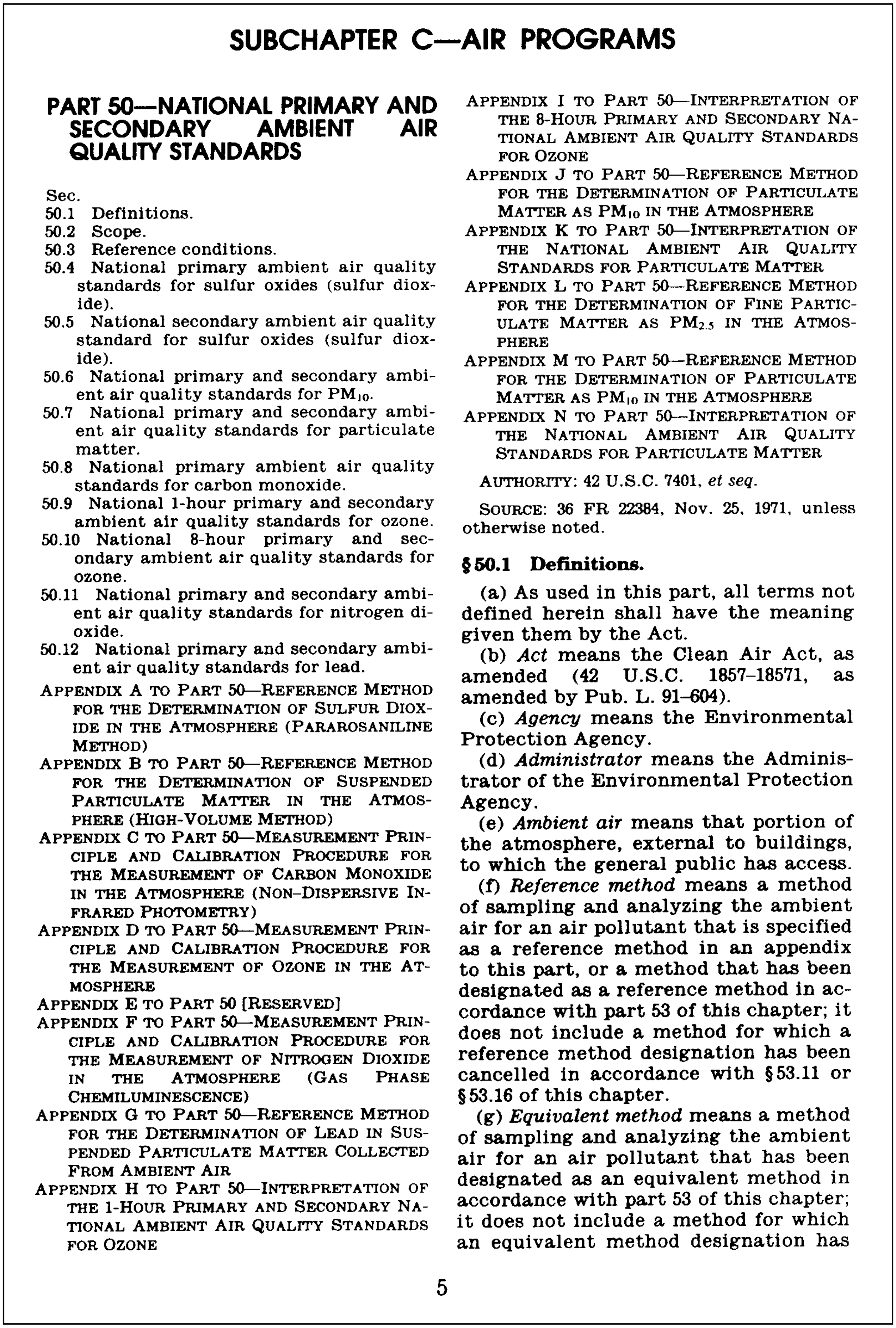
Each section has a table of contents that lists the part number on the left and the section number on the right, separated by a period.

Authority Citation

The authority citation following the Table of Contents is provided, and kept current, by the appropriate administrative agency. The citation provides the legislative (or statutory) authority under which a part, or section within a part is issued.

Source Note

The Office of the Federal Register supplies the source note. This note tells where the codified material was last published in the *Federal Register* and is listed in full by volume, page, and date. The source note for the entire part follows the authority citation. If a section is added or amended later, the source note would follow the text of that section.



SUBCHAPTER C—AIR PROGRAMS

PART 50—NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

AUTHORITY: 42 U.S.C. 7401, *et seq.*

SOURCE: 36 FR 22384, Nov. 25, 1971, unless otherwise noted.

§ 50.1 Definitions.

(a) As used in this part, all terms not defined herein shall have the meaning given them by the Act.

(b) *Act* means the Clean Air Act, as amended (42 U.S.C. 1857–18571, as amended by Pub. L. 91–604).

(c) *Agency* means the Environmental Protection Agency.

(d) *Administrator* means the Administrator of the Environmental Protection Agency.

(e) *Ambient air* means that portion of the atmosphere, external to buildings, to which the general public has access.

(f) *Reference method* means a method of sampling and analyzing the ambient air for an air pollutant that is specified as a reference method in an appendix to this part, or a method that has been designated as a reference method in accordance with part 53 of this chapter; it does not include a method for which a reference method designation has been cancelled in accordance with § 53.11 or § 53.16 of this chapter.

(g) *Equivalent method* means a method of sampling and analyzing the ambient air for an air pollutant that has been designated as an equivalent method in accordance with part 53 of this chapter; it does not include a method for which an equivalent method designation has been cancelled in accordance with § 53.11 or § 53.16 of this chapter.

(h) *Traceable* means that a local standard has been compared and certified either directly or via not more than one intermediate standard, to a primary standard such as a National Bureau of Standards Standard Reference Material (NBS SRM), or a USEPA/NBS-approved Certified Reference Material (CRM).

(i) *Indian country* is as defined in 18 U.S.C. 1151.

[36 FR 22384, Nov. 25, 1971, as amended at 41 FR 11253, Mar. 17, 1976; 48 FR 2529, Jan. 20, 1983; 63 FR 7274, Feb. 12, 1998]

§ 50.2 Scope.

(a) National primary and secondary ambient air quality standards under section 109 of the Act are set forth in this part.

(b) National primary ambient air quality standards define levels of air quality which the Administrator judges are necessary, with an adequate margin of safety, to protect the public health. National secondary ambient air quality standards define levels of air quality which the Administrator judges necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Such standards are subject to revision, and additional primary and secondary standards may be promulgated as the Administrator deems necessary to protect the public health and welfare.

(c) The promulgation of national primary and secondary ambient air quality standards shall not be considered in any manner to allow significant deterioration of existing air quality in any portion of any State or Indian country.

(d) The proposal, promulgation, or revision of national primary and secondary ambient air quality standards shall not prohibit any State or Indian country from establishing ambient air quality standards for that State or area under a tribal CAA program or any portion thereof which are more stringent than the national standards.

[36 FR 22384, Nov. 25, 1971, as amended at 63 FR 7274, Feb. 12, 1998]

§ 50.3 Reference conditions.

All measurements of air quality that are expressed as mass per unit volume (e.g., micrograms per cubic meter) other than for the particulate matter (PM_{10} and $PM_{2.5}$) standards contained in § 50.7 shall be corrected to a reference temperature of 25 °C and a reference pressure of 760 millimeters of mercury (1,013.2 millibars). Measurements of PM_{10} and $PM_{2.5}$ for purposes of comparison to the standards contained in § 50.7 shall be reported based on actual ambient air volume measured at the actual ambient temperature and pressure at the monitoring site during the measurement period.

[62 FR 38711, July 18, 1997]

§ 50.4 National primary ambient air quality standards for sulfur oxides (sulfur dioxide).

(a) The level of the annual standard is 0.030 parts per million (ppm), not to be exceeded in a calendar year. The annual arithmetic mean shall be rounded to three decimal places (fractional parts equal to or greater than 0.0005 ppm shall be rounded up).

(b) The level of the 24-hour standard is 0.14 parts per million (ppm), not to be exceeded more than once per calendar year. The 24-hour averages shall be determined from successive nonoverlapping 24-hour blocks starting at midnight each calendar day and shall be rounded to two decimal places (fractional parts equal to or greater than 0.005 ppm shall be rounded up).

(c) Sulfur oxides shall be measured in the ambient air as sulfur dioxide by the reference method described in appendix A to this part or by an equivalent method designated in accordance with part 53 of this chapter.

(d) To demonstrate attainment, the annual arithmetic mean and the second-highest 24-hour averages must be based upon hourly data that are at least 75 percent complete in each calendar quarter. A 24-hour block average shall be considered valid if at least 75 percent of the hourly averages for the 24-hour period are available. In the event that only 18, 19, 20, 21, 22, or 23 hourly averages are available, the 24-hour block average shall be computed as the sum of the available hourly averages using 18, 19, etc. as the divisor. If fewer than 18 hourly averages are available, but the 24-hour average would exceed the level of the standard when zeros are substituted for the missing values, subject to the rounding rule of paragraph (b) of this section, then this shall be considered a valid 24-hour average. In this case, the 24-hour block average shall be computed as the sum of the available hourly averages divided by 24.

[61 FR 25579, May 22, 1996]

§ 50.5 National secondary ambient air quality standard for sulfur oxides (sulfur dioxide).

(a) The level of the 3-hour standard is 0.5 parts per million (ppm), not to be exceeded more than once per calendar year. The 3-hour averages shall be determined from successive nonoverlapping 3-hour blocks starting at midnight each calendar day and shall be rounded to 1 decimal place (fractional parts equal to or greater than 0.05 ppm shall be rounded up).

(b) Sulfur oxides shall be measured in the ambient air as sulfur dioxide by the reference method described in appendix A of this part or by an equivalent method designated in accordance with part 53 of this chapter.

(c) To demonstrate attainment, the second-highest 3-hour average must be based upon hourly data that are at least 75 percent complete in each calendar quarter. A 3-hour block average shall be considered valid only if all three hourly averages for the 3-hour period are available. If only one or two hourly averages are available, but the 3-hour average would exceed the level of the standard when zeros are substituted for the missing values, subject to the rounding rule of paragraph (a) of this section, then this shall be considered a valid 3-hour average. In all cases, the 3-hour block average shall be computed as the sum of the hourly averages divided by 3.

[61 FR 25580, May 22, 1996]

§ 50.6 National primary and secondary ambient air quality standards for PM_{10}.

(a) The level of the national primary and secondary 24-hour ambient air quality standards for particulate matter is 150 micrograms per cubic meter ($\mu g/m^3$), 24-hour average concentration. The standards are attained when the expected number of days per calendar year with a 24-hour average concentration above 150 $\mu g/m^3$, as determined in accordance with appendix K to this part, is equal to or less than one.

(b) The level of the national primary and secondary annual standards for particulate matter is 50 micrograms per cubic meter ($\mu g/m^3$), annual arithmetic mean. The standards are attained when the expected annual arithmetic mean concentration, as determined in accordance with appendix K to this part, is less than or equal to 50 $\mu g/m^3$.

(c) For the purpose of determining attainment of the primary and secondary standards, particulate matter shall be measured in the ambient air as PM_{10} (particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers) by:

(1) A reference method based on appendix J and designated in accordance with part 53 of this chapter, or

(2) An equivalent method designated in accordance with part 53 of this chapter.

(d) The PM_{10} standards set forth in this section will no longer apply to an area not attaining these standards as of September 16, 1997, once EPA takes final action to promulgate a rule pursuant to section 172(e) of the Clean Air Act, as amended (42 U.S.C. 7472(e)) applicable to the area. The PM_{10} standards set forth in this section will no longer apply to an area attaining these standards as of September 16, 1997, once EPA approves a State Implementation Plan (SIP) applicable to the area containing all PM_{10} control measures adopted and implemented by the State prior to September 16, 1997, and a section 110 SIP implementing the PM standards published on July 18, 1997.

SIP approvals are codified in 40 CFR part 52.

[52 FR 24663, July 1, 1987, as amended at 62 FR 38711, July 18, 1997]

§ 50.7 National primary and secondary ambient air quality standards for particulate matter.

(a) The national primary and secondary ambient air quality standards for particulate matter are:

(1) 15.0 micrograms per cubic meter (µg/m^3) annual arithmetic mean concentration, and 65 µg/m^3 24-hour average concentration measured in the ambient air as $PM_{2.5}$ (particles with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers) by either:

(i) A reference method based on appendix L of this part and designated in accordance with part 53 of this chapter; or

(ii) An equivalent method designated in accordance with part 53 of this chapter.

(2) 50 micrograms per cubic meter (µg/m^3) annual arithmetic mean concentration, and 150 µg/m^3 24-hour average concentration measured in the ambient air as PM_{10} (particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers) by either:

(i) A reference method based on appendix M of this part and designated in accordance with part 53 of this chapter; or

(ii) An equivalent method designated in accordance with part 53 of this chapter.

(b) The annual primary and secondary $PM_{2.5}$ standards are met when the annual arithmetic mean concentration, as determined in accordance with appendix N of this part, is less than or equal to 15.0 micrograms per cubic meter.

(c) The 24-hour primary and secondary $PM_{2.5}$ standards are met when the 98th percentile 24-hour concentration, as determined in accordance with appendix N of this part, is less than or equal to 65 micrograms per cubic meter.

(d) The annual primary and secondary PM_{10} standards are met when the annual arithmetic mean concentration, as determined in accordance with appendix N of this part, is less than or equal to 50 micrograms per cubic meter.

(e) The 24-hour primary and secondary PM_{10} standards are met when the 99th percentile 24-hour concentration, as determined in accordance with appendix N of this part, is less than or equal to 150 micrograms per cubic meter.

[62 FR 38711, July 18, 1997]

§ 50.8 National primary ambient air quality standards for carbon monoxide.

(a) The national primary ambient air quality standards for carbon monoxide are:

(1) 9 parts per million (10 milligrams per cubic meter) for an 8-hour average concentration not to be exceeded more than once per year and

(2) 35 parts per million (40 milligrams per cubic meter) for a 1-hour average concentration not to be exceeded more than once per year.

(b) The levels of carbon monoxide in the ambient air shall be measured by:

(1) A reference method based on appendix C and designated in accordance with part 53 of this chapter, or

(2) An equivalent method designated in accordance with part 53 of this chapter.

(c) An 8-hour average shall be considered valid if at least 75 percent of the hourly average for the 8-hour period are available. In the event that only six (or seven) hourly averages are available, the 8-hour average shall be computed on the basis of the hours available using six (or seven) as the divisor.

(d) When summarizing data for comparision with the standards, averages shall be stated to one decimal place. Comparison of the data with the levels of the standards in parts per million shall be made in terms of integers with fractional parts of 0.5 or greater rounding up.

[50 FR 37501, Sept. 13, 1985]

§ 50.9 National 1-hour primary and secondary ambient air quality standards for ozone.

(a) The level of the national 1-hour primary and secondary ambient air quality standards for ozone measured by a reference method based on appendix D to this part and designated in accordance with part 53 of this chapter, is 0.12 parts per million (235 μg/m^3). The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 parts per million (235 μg/m^3) is equal to or less than 1, as determined by appendix H to this part.

(b) The 1-hour standards set forth in this section will no longer apply to an area once EPA determines that the area has air quality meeting the 1-hour standard. Area designations are codified in 40 CFR part 81.

[62 FR 38894, July 18, 1997]

§50.10 National 8-hour primary and secondary ambient air quality standards for ozone.

(a) The level of the national 8-hour primary and secondary ambient air quality standards for ozone, measured by a reference method based on appendix D to this part and designated in accordance with part 53 of this chapter, is 0.08 parts per million (ppm), daily maximum 8-hour average.

(b) The 8-hour primary and secondary ozone ambient air quality standards are met at an ambient air quality monitoring site when the average of the annual fourth-highest daily maximum 8-hour average ozone concentration is less than or equal to 0.08 ppm, as determined in accordance with appendix I to this part.

[62 FR 38894, July 18, 1997]

§50.11 National primary and secondary ambient air quality standards for nitrogen dioxide.

(a) The level of the national primary ambient air quality standard for nitrogen dioxide is 0.053 parts per million (100 micrograms per cubic meter), annual arithmetic mean concentration.

(b) The level of national secondary ambient air quality standard for nitrogen dioxide is 0.053 parts per million (100 micrograms per cubic meter), annual arithmetic mean concentration.

(c) The levels of the standards shall be measured by:

(1) A reference method based on appendix F and designated in accordance with part 53 of this chapter, or

(2) An equivalent method designated in accordance with part 53 of this chapter.

(d) The standards are attained when the annual arithmetic mean concentration in a calendar year is less than or equal to 0.053 ppm, rounded to three decimal places (fractional parts equal to or greater than 0.0005 ppm must be rounded up). To demonstrate attainment, an annual mean must be based upon hourly data that are at least 75 percent complete or upon data derived from manual methods that are at least 75 percent complete for the scheduled sampling days in each calendar quarter.

[50 FR 25544, June 19, 1985]

§50.12 National primary and secondary ambient air quality standards for lead.

National primary and secondary ambient air quality standards for lead and its compounds, measured as elemental lead by a reference method based on appendix G to this part, or by an equivalent method, are: 1.5 micrograms per cubic meter, maximum arithmetic mean averaged over a calendar quarter.

(Secs. 109, 301(a) Clean Air Act as amended (42 U.S.C. 7409, 7601(a)))

[43 FR 46258, Oct. 5, 1978]

APPENDIX A TO PART 50—REFERENCE METHOD FOR THE DETERMINATION OF SULFUR DIOXIDE IN THE ATMOSPHERE (PARAROSANILINE METHOD)

1.0 *Applicability.*

1.1 This method provides a measurement of the concentration of sulfur dioxide (SO_2) in ambient air for determining compliance with the primary and secondary national ambient air quality standards for sulfur oxides (sulfur dioxide) as specified in §50.4 and §50.5 of this chapter. The method is applicable to the measurement of ambient SO_2 concentrations using sampling periods ranging from 30 minutes to 24 hours. Additional quality assurance procedures and guidance are provided in part 58, appendixes A and B, of this chapter and in references 1 and 2.

2.0 *Principle.*

2.1 A measured volume of air is bubbled through a solution of 0.04 M potassium tetrachloromercurate (TCM). The SO_2 present in the air stream reacts with the TCM solution to form a stable monochlorosulfonatomercurate(*3*) complex. Once formed, this complex resists air oxidation(*4*,

5) and is stable in the presence of strong oxidants such as ozone and oxides of nitrogen. During subsequent analysis, the complex is reacted with acid-bleached pararosaniline dye and formaldehyde to form an intensely colored pararosaniline methyl sulfonic acid.(*6*) The optical density of this species is determined spectrophotometrically at 548 nm and is directly related to the amount of SO_2 collected. The total volume of air sampled, corrected to EPA reference conditions (25 °C, 760 mm Hg [101 kPa]), is determined from the measured flow rate and the sampling time. The concentration of SO_2 in the ambient air is computed and expressed in micrograms per standard cubic meter (µg/std m^3).

3.0 *Range.*

3.1 The lower limit of detection of SO_2 in 10 mL of TCM is 0.75 µg (based on collaborative test results).(*7*) This represents a concentration of 25 µg SO_2/m^3 (0.01 ppm) in an air sample of 30 standard liters (short-term sampling) and a concentration of 13 µg SO_2/m^3 (0.005 ppm) in an air sample of 288 standard liters (long-term sampling). Concentrations less than 25 µg SO_2/m^3 can be measured by sampling larger volumes of ambient air; however, the collection efficiency falls off rapidly at low concentrations.(*8, 9*) Beer's law is adhered to up to 34 µg of SO_2 in 25 mL of final solution. This upper limit of the analysis range represents a concentration of 1,130 µg SO_2/m^3 (0.43 ppm) in an air sample of 30 standard liters and a concentration of 590 µg SO_2/m^3 (0.23 ppm) in an air sample of 288 standard liters. Higher concentrations can be measured by collecting a smaller volume of air, by increasing the volume of absorbing solution, or by diluting a suitable portion of the collected sample with absorbing solution prior to analysis.

4.0 *Interferences.*

4.1 The effects of the principal potential interferences have been minimized or eliminated in the following manner: Nitrogen oxides by the addition of sulfamic acid,(*10, 11*) heavy metals by the addition of ethylenediamine tetracetic acid disodium salt (EDTA) and phosphoric acid,(*10, 12*) and ozone by time delay.(*10*) Up to 60 µg Fe (III), 22 µg V (V), 10 µg Cu (II), 10 µg Mn (II), and 10 µg Cr (III) in 10 mL absorbing reagent can be tolerated in the procedure.(*10*) No significant interference has been encountered with 2.3 µg NH_3.(*13*)

5.0 *Precision and Accuracy.*

5.1 The precision of the analysis is 4.6 percent (at the 95 percent confidence level) based on the analysis of standard sulfite samples.(*10*)

5.2 Collaborative test results(*14*) based on the analysis of synthetic test atmospheres (SO_2 in scrubbed air) using the 24-hour sampling procedure and the sulfite-TCM calibration procedure show that:

- The replication error varies linearly with concentration from ±2.5 µg/m^3 at concentrations of 100 µg/m^3 to ±7 µg/m^3 at concentrations of 400 µg/m^3.
- The day-to-day variability within an individual laboratory (repeatability) varies linearly with concentration from ±18.1 µg/m^3 at levels of 100 µg/m^3 to ±50.9 µg/m^3 at levels of 400 µg/m^3.
- The day-to-day variability between two or more laboratories (reproducibility) varies linearly with concentration from ±36.9 µg/m^3 at levels of 100 µg/m^3 to ±103.5 µ g/m^3 at levels of 400 µg/m^3.
- The method has a concentration-dependent bias, which becomes significant at the 95 percent confidence level at the high concentration level. Observed values tend to be lower than the expected SO_2 concentration level.

6.0 *Stability.*

6.1 By sampling in a controlled temperature environment of 15°±10 °C, greater than 98.9 percent of the SO_2–TCM complex is retained at the completion of sampling.(*15*) If kept at 5 °C following the completion of sampling, the collected sample has been found to be stable for up to 30 days.(*10*) The presence of EDTA enhances the stability of SO_2 in the TCM solution and the rate of decay is independent of the concentration of SO_2.(*16*)

7.0 *Apparatus.*

7.1 *Sampling.*

7.1.1 *Sample probe:* A sample probe meeting the requirements of section 7 of 40 CFR part 58, appendix E (Teflon® or glass with residence time less than 20 sec.) is used to transport ambient air to the sampling train location. The end of the probe should be designed or oriented to preclude the sampling of precipitation, large particles, etc. A suitable probe can be constructed from Teflon® tubing connected to an inverted funnel.

7.1.2 *Absorber—short-term sampling:* An all glass midget impinger having a solution capacity of 30 mL and a stem clearance of 4±1 mm from the bottom of the vessel is used for sampling periods of 30 minutes and 1 hour (or any period considerably less than 24 hours). Such an impinger is shown in Figure 1. These impingers are commercially available from distributors such as Ace Glass, Incorporated.

7.1.3 *Absorber—24-hour sampling:* A polypropylene tube 32 mm in diameter and 164 mm long (available from Bel Art Products, Pequammock, NJ) is used as the absorber. The cap of the absorber must be a polypropylene cap with two ports (rubber stoppers are unacceptable because the absorbing reagent can react with the stopper to yield erroneously high SO_2 concentrations). A glass impinger stem, 6 mm in diameter and 158 mm long, is inserted into one port of the absorber cap. The tip of the stem is tapered to a small diameter orifice (0.4±0.1 mm) such that a No. 79 jeweler's drill bit will pass through the opening but a No. 78 drill bit

Code of Federal Regulations
Practical Exercise

Directions: *Review the following CFR information and complete the research questions in the space provided.*

18. The appropriate Title for *CFR* regulations governing the Internal Revenue Service is

a. Title 9
b. Title 14
c. Title 26
d. Title 40
e. Title 49

18.________

19. Administrative agencies in the Pentagon can expect *CFR* updates governing the National Defense not later than

a. January 1
b. April 1
c. July 1
d. October 1
e. December 1

19. ________

20. The citation 40 CFR 61 are regulations governing

a. OMB approvals under the Paperwork Reduction Act.
b. National emission standards for hazardous air pollutants.
c. Federal operating permit programs.
d. Control of air pollution from motor vehicles and motor vehicle engines.
e. Mandatory patent licenses.

20. ________

21. The proper citation for “Continuous emission monitoring” regulations is

a. 20 CFR 40
b. 40 CFR 20
c. 40 CFR 75
d. 75 CFR 40
e. 40 CFR 50

21. ________

22. Which Appendix could you consult to obtain the most current information regarding “Reference Methods for the Determination of Particulate Matter as $PM_{2.5}$ in the Atmosphere”?

a. Appendix A
b. Appendix D
c. Appendix H
d. Appendix L
e. Appendix N

22. ________

23. What is the National primary ambient air quality standard for sulfur dioxide?

a. .03 ppm
b. .05 ppm
c. .50 ppm
d. .14 ppm
e. .95 ppm **23.** ________

24. Where would you go to read the full text of the regulations governing “National secondary ambient air quality standards for sulfur oxides”?

a. Slip Law
b. 61 FR 25580
c. 40 CFR 50
d. Office of Air Quality Planning and Standards
e. Appendix A to Part 50 **24.** ________

25. When were the national primary and secondary ambient air quality standards for particulate matter last revised?

a. May 22, 1996
b. July 1, 1987
c. July 18, 1997
d. September 13, 1985
e. October 5, 1978 **25.** ________

26. What is the 1-hour national primary ambient air quality standard for carbon monoxide?

a. 9 parts / million
b. 35 parts / million
c. 15.0 μm / m^3
d. 50 μm / m^3
e. 150 μm / m^3 **26.** ________

27. According to Appendix A, the accuracy of reference methods used to determine the amount of sulfur dioxide in the atmosphere (at the 95% confidence level) is ____________________.

28. According to Appendix A, a suitable sampling probe that may be used to measure the amount of sulfur dioxide in the atmosphere may be constructed from _____________________________.

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	C	13-8
2.	E	13-7
3.	A	13-3
4.	C	13-12
5.	D	13-12
6.	A	13-4
7.	B	13-4
8.	C	13-8
9.	C	13-10
10.	A	13-7
11.	B	13-3→13-11
12.	D	
13.	F	
14.	A	
15.	G	
16.	E	
17.	C	
18.	C	
19.	C	
20.	B	
21.	C	
22.	D	
23.	D	
24.	B	
25.	C	
26.	B	
27.	4.6%	
28.	Teflon tubing connected to an inverted funnel.	

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CHAPTER 14

Compliance and Enforcement

Lesson Goal

Demonstrate an understanding of the different enforcement systems utilized to bring source into compliance with air pollution regulations. Describe how the enforcement process is implemented, and the various roles of federal, state, and local authorities for air pollution enforcement. This goal will be met on successful completion of the review questions at the end of the chapter.

Lesson Objectives

1. Describe the five systems of enforcement.
2. Identify how construction and operating permits aid enforcement.
3. List the different steps in conducting an air pollution inspection.
4. Detail the EPA's new compliance monitoring strategy, and what the three compliance monitoring categories.
5. Describe how the enforcement process is implemented.
6. Explain the various roles of federal, state, and local authorities of air pollution enforcement.

Recommended Reading: "Conducting Environmental Compliance Inspections, Inspector's Field Manual Eight Edition," EPA 910/91-047, Nov. 1997.

References

Bedrock, N.R., 1993, “Enforcing the CAA,” *Environmental Protection*, November, pp.10-14.

U.S. Code of Federal Regulations, 40 CRF 51.

U.S. EPA, *Air Compliance Inspection Manual*, EPA-340/1-85-020,1985.

U.S. EPA, *Air Pollution Orientation* Course, Alpha Gamma Technologies, 1992.

U.S. EPA, *Air Pollution Field Enforcement: Student Manual*, APTI Course 444, 1999.

U.S. EPA, *Clean Air Act: Compliance/Enforcement Guidance Manual*, 1984.

U.S. EPA, *Clean Air Act: Stationary Source Compliance Monitoring Strategy*, April 2001.

U.S. EPA, *Conducting Environmental Compliance Inspections, Inspector’s Field Manual Eight Edition*, EPA 910/91-047, November 1997.

Compliance and Enforcement

The mission of the enforcement operations of an agency is to carry out those field tasks designed to bring sources into compliance with regulations at the earliest possible time and to maintain their compliance. Enforcement actions vary widely among agencies, and policies setting enforcement strategy are as individualistic as the agencies themselves. This chapter presents various enforcement mechanisms. Although inspectors are not free to choose from the mechanisms available, it is hoped this chapter will widen their perspective of enforcement.

Enforcement Systems

Control strategies are woven into five enforcement systems for implementation: (a) permits to construct and operate; (b) compliance monitoring; (c) compliance plan enforcement; (d) surveillance and complaint response: and (e) initiation of an enforcement action (response).

Enforcement Mechanisms

- *Permits to construct and operate*
- *Compliance monitoring*
- *Compliance plan enforcement*
- *Surveillance and complaints*
- *Enforcement action*

Permits to Construct. The purpose of this permit is to prevent construction of a new stationary source or modification of an existing source, if emissions from that source would: (a) result in a violation of applicable portions of the control strategy; (b) prevent attainment or maintenance of one or more of the National Ambient Air Quality Standards (NAAQS); or (c) cause significant deterioration of air quality which is currently better than that required by the NAAQS.

The permit systems aid enforcement and may also aid the applicant by: (a) providing for engineering review prior to construction, so any necessary changes can be made with less cost than after construction begins (not applicable to registration); (b) preventing construction before it starts if the new source does not comply in all respects; (c) requiring, if needed, that the permit documents highlight parameters which are important to proper functioning of the control equipment; (d) insuring that required emission monitors will be installed; (e) requiring, in some cases, that the permit document include an operations and maintenance program; (f) denying operating permits if inspection or tests show noncompliance, so the source cannot legally operate until it is in compliance; (g) giving notice of change when adding, modifying or deleting sources; (h) keeping the emission inventory up to date; and (i) acting as a good continuing training program by having the inspector do the permit inspections, allowing a view of the equipment as it is being constructed.

Uniform Permit Program

- *Application for operation permit*
- *Regular monitoring and reporting requirements*
- *Annual renewal fee*
- *Minimum training requirements*
- *U.S. EPA authority to regulate*

Operating Permits. The Clean Air Act Amendments of 1990 conditioned industrial operations on stringent regulations for the release of pollutants into the atmosphere. Title V of the CAA Amendments directed the U.S. EPA to construct a uniform permit program based on the following elements: (1) standard application with specific criteria for approval, (2) regular monitoring and reporting requirements, (3) payment of an annual renewal fee, (4) maintain minimum training requirements for site staff, and (5) establish U.S. EPA authority to issue permits and assure compliance.

Requiring sources to file applications for renewal of their operating permit on a regular time cycle is a strong enforcement tool. The purpose is to set up a scheduled review of all sources and reissue or deny an operating permit where compliance or noncompliance is the result of the evaluation process. Operating permits aid enforcement by:

a. Subjecting sources to periodic review.

b. Allowing the denial of an operating permit, making operation of a source a violation.

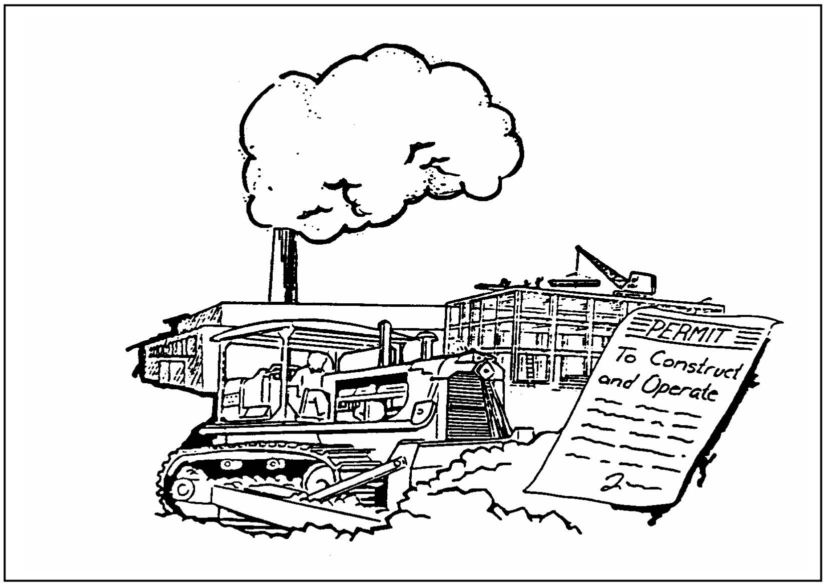
c. Providing a periodic update of the original permit documents regarding ownership change, process change, materials change, etc.

d. Updating emission inventory

e. Providing a systematic check of compliance status by:

- Observing visible emissions
- Inspecting emission monitors and control device instrumentation
- Reviewing recorded emissions data
- Inspecting control devices for good operating and maintenance procedures

The purpose of the permit system is to track information about sources of air pollution, to establish appropriate elements of a control program, and to evaluate future management strategies. Effective government regulation requires sources of air pollution to obtain a permit to construct and operate a facility. The permitting requirements are necessary for control agencies to accurately maintain current information about the type and location of all air pollution sources, as well as the type and quantity of their emissions.



The purpose of the permit system is to track information about sources of air pollution, to establish appropriate elements of a control program, and to evaluate future management strategies.

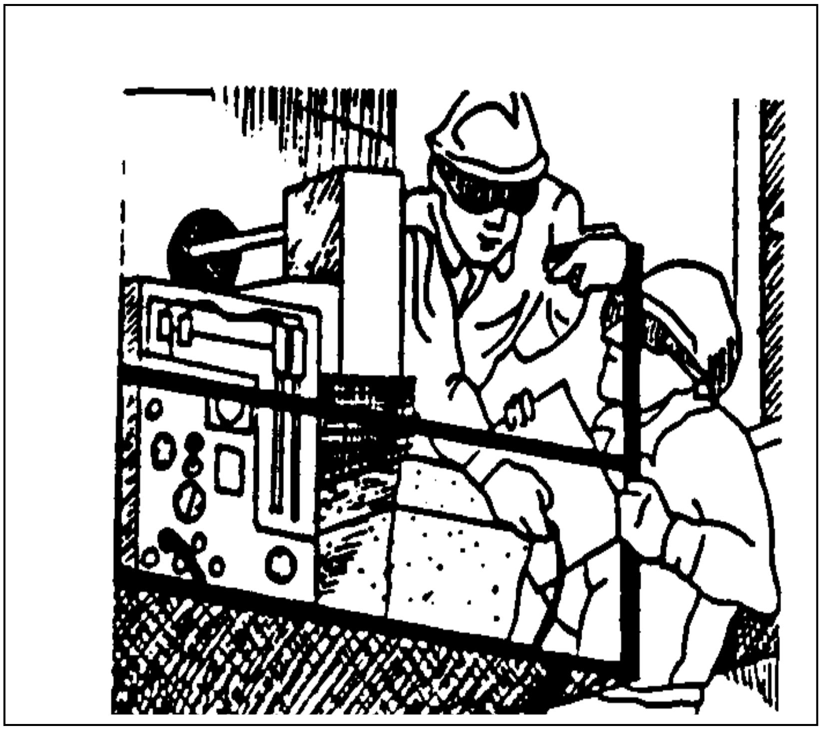
The goal of the permit system is to ensure that every facility accurately details each source of its air pollution. The permit includes emissions criteria for each source, a schedule of compliance, monitoring and reporting criteria, and other miscellaneous provisions. The purpose of a U.S. EPA permit to operate is that it reduces pertinent information about each facility to one document and creates a contractual agreement between government regulatory agencies and private industry for continued operation.

Compliance Monitoring and Inspections. Compliance monitoring is a system used by regulatory agencies to determine if environmental laws and regulations are being obeyed. Two types of compliance monitoring are used: continuous, self-monitoring of a regulated facility and compliance inspections.

Most state regulatory agencies require that certain facilities self-monitor and report their compliance status. The proliferation of industrial sites coupled with declining resources for state inspection teams make the full participation of each facility an essential part of proper compliance. A typical monitoring regulation will specify a facility's duty to monitor and report accurate records of pollutant emissions and will specify emission levels for each criteria pollutant within the facility. Full compliance with the terms of the self-monitoring agreement is frequently a condition of a site's continued operation.

Another means of assuring compliance with statutory law is through the use of announced or unannounced facility inspections. The purpose of such an inspection is to evaluate the compliance status of an operational facility,

The purpose of a facility inspection is to evaluate the compliance of a facility, gather evidence of misconduct, and create a visible presence of enforcement at regulated facilities.



gather evidence of misconduct, and create a visible presence of enforcement personnel at regulated facilities. When there are seldom enough inspection teams to conduct regular, routine site visits, sometimes simply the “threat” of an inspection is enough to deter violations at a facility.

Inspections can be in the form of a routine plant visit, inspections prompted by a complaint or suspicion of violation, or a follow-up inspection from a previous complaint. Ideally, every regulated facility should be inspected on a regular basis; however, no agency has the manpower or resources to conduct regular inspections of every facility within its jurisdiction. For this reason, regulatory agencies must establish inspection priorities. Not terribly unlike other businesses that experience periods of limited resources, a triage list can be developed to classify all facilities that represent the greatest risk to human health and the environment. Under pressing or critical circumstances, the list may be composed simply of those who have the worst records of compliance. Creating such a classification, however, can greatly assist regulatory agencies as they develop inspection schedules and set priorities for assuring industrial compliance.

There are four main objectives to a compliance monitoring inspection:

a. Observe the facility and identify specific environmental problems, if any exist. This information will enable EPA to determine whether the facility is in compliance.

b. Provide EPA with facts about a facility or site’s compliance status and ensure the quality of self-reported information.

c. Collect and preserve evidence of any specific problems that appear to be violations.

d. The inspection itself displays a regulatory awareness that acts as a deterrent to further violations by the facility.

Compliance Monitoring

- *Inspect for violations*
- *Document facility compliance*
- *Collect and preserve evidence*
- *Deter future violations*

Conducting an Inspection. There are five steps in conducting an inspection:

a. *Review rules and source records*. Obtain basic facility information (i.e., names, titles, maps, process flow diagrams, and potential safety hazardous). Review applicable federal, state, and local laws and regulations, and review the facility's compliance and enforcement history (i.e., self-reporting data and reports). Study the most recent permits for the facility and find the acceptable operating conditions and any special conditions, exemptions or waivers.

b. *Prepare an inspection plan.* Know the purpose of the inspection and the tasks necessary to accomplish it. Prepare an inspection schedule.

c. *Enter the facility and hold an opening conference*: The purpose of this meeting is to inform the plant official of the purpose of the inspection, the authority under which it will be conducted, and the procedures to be followed.

Facility Inspection Procedure

- *Review rules and records*
- *Prepare inspection plan*
- *Opening conference*
- *Conduct inspection*
- *Prepare report*

d. *Conduct an inspection, obtain samples, and hold a closing conference.* A post-inspection meeting should be scheduled with the appropriate facility officials to provide a final opportunity to gather information, answer questions, and make confidentiality declarations. Facility officials should be informed of their right to receive a duplicate of any sample collected for laboratory analysis or to conduct simultaneous measurements.

e. *Prepare a report.* The inspection report serves two purposes: It provides the agency easy access to facility information, and it constitutes a major part of evidence for subsequent enforcement actions. This report should be accurate, relevant, comprehensive, coordinated, objective, well organized, neat and legible.

Compliance Monitoring Strategy. In April of 2001, the USEPA revised the Clean Air Act Stationary Source Compliance Monitoring Strategy (CMS). The revised policy replaces the 1991 CMS. The major changes to the policy are as follows:

a. Emphasis has been placed on Title V major sources and a limited subset of synthetic minor sources.

b. Minimum frequencies have been recommended for determining the compliance status of facilities covered by this policy. Alternatives may be developed and negotiated with the Regions to enable States/locals to address important local compliance issues.

c. The policy explicitly recognizes that a variety of tools ranging from self-certifications to traditional stack tests are available and should be used to evaluate compliance. It further recognizes that on-site visits may not be necessary to evaluate the compliance status of a facility given the wide range of self-reported information such as annual Title V compliance certifications, deviation reports, and semiannual monitoring reports based on periodic monitoring and compliance assurance monitoring. However, to ensure a compliance presence in the field, a minimum frequency for on-site visits has been recommended.

d. Three categories of compliance monitoring replace the current levels of inspection defined in the 1987 Clean Air Act Compliance/Enforcement Guidance Manual. The new compliance monitoring categories are: Full Compliance Evaluations, Partial Compliance Evaluations and Investigations.

e. CMS plans are no longer required to be submitted every year, but may be submitted once every two years.

The main goal of the new 2001 compliance monitoring strategy is to provide national consistency in developing stationary source air compliance monitoring programs, while simultaneously providing States/locals flexibility to address local air pollution and compliance concerns.

The new 2001 strategy outlines the following process for implementation of Regions/State/local compliance monitoring strategy plans:

a. States/locals submit a CMS plan biennially for discussion with and approval by the Regions. Regions also prepare a plan biennially for discussion with their States/locals.

b. The plans are summarized, and incorporated into the annual Regional response to the OECA Memorandum of Agreement (MOA).

c. States/locals and Regions maintain records of their compliance monitoring activities, and enter facility-specific compliance data in the national air compliance database (AIRS/AFS, or its successor).

d. States/locals and Regions review the results of the compliance monitoring activities annually, and prepare an annual update to the biennial plan as necessary. Major redirections are discussed as they arise.

e. Regions conduct in-depth evaluations of the overall State/local compliance-monitoring program periodically. Headquarters conducts similar evaluations of the Regional programs as well.

Three compliance monitoring categories under the 2001 CMS.

1.Full Compliance Evaluations

2.Partial Compliance Evaluations

3.Investigations

Compliance Monitoring Categories. The 2001 CMS defines three categories of compliance monitoring: Full Compliance Evaluations, Partial Compliance Evaluations, and Investigations. They are defined as Full Compliance Evaluations.

Full Compliance Evaluations

A Full Compliance Evaluation is a comprehensive evaluation of the compliance status of a facility. It addresses all regulated pollutants at all regulated emission units. Furthermore, it addresses the current compliance status of each emission unit, as well as the facility’s continuing ability to maintain compliance at each emission unit.

It should include the following:

- A review of all required reports, and to the extent necessary, the underlying records. This includes all monitored data reported to the regulatory agency (i.e., CEM and continuous parameter monitoring reports, malfunction reports, excess emission reports). It also includes a review of Title V self-certifications, semi-annual monitoring and periodic monitoring reports, and any other reports required by permit.

- An assessment of control device and process operating conditions as appropriate. An on-site visit to make this assessment may not be necessary based on factors such as the availability of continuous emission and periodic monitoring data, compliance certifications, and deviation reports. Examples of source categories that may not require an on-site visit to assess compliance include, but are not limited to, gas-fired compressor stations, boilers in large office and apartment buildings, peaking stations, and gas turbines.

- A visible emission observation as needed.

- A review of facility records and operating logs.

- An assessment of process parameters such as feed rates, raw material compositions, and process rates.

- An assessment of control equipment performance parameters (i.e., water flow rates, pressure drop, temperature, and electrostatic precipitator power levels)

- A stack test where there is no other means for determining compliance with the emission limits. In determining whether a stack test is necessary, States/locals should consider factors such as: size of emission unit; time elapsed since last stack test; results of that test and margin of compliance; condition of control equipment; and availability and results of associated monitoring data. In addition to conducting a stack test when there is no other means of determining compliance, States/locals should conduct a stack test whenever they deem appropriate.

A Full Compliance Evaluation should be conducted, at a minimum, once every two years at all Title V major sources except those classified as mega-sites (extremely large sites). For mega-sites, a Full Compliance Evaluation should be conducted, at a minimum, once every three years.

A Full Compliance Evaluation should be conducted, at a minimum, once every five years at synthetic minor sources that emit or have the potential to emit at or above 80 percent of the Title V major source threshold.

An on-site visit should be conducted, at a minimum, once every five years at all Title V major sources to ensure a compliance presence in the field, verify record reviews, observe modifications or new construction, and identify any major permit deviations.

A Full Compliance Evaluation may be done piecemeal through a series of Partial Compliance Evaluations.

Partial Compliance Evaluations

A Partial Compliance Evaluation is a documented compliance assessment focusing on a subset of regulated pollutants, regulatory requirements, or emission units at a given facility. A Partial Compliance Evaluation should be more comprehensive than a cursory review of individual reports. It may be conducted solely for the purpose of evaluating a specific aspect of a facility, or combined over the course of a year (or up to three years at mega-sites) to satisfy the requirements of a Full Compliance Evaluation.

This type of evaluation could be used for example to effectively assess compliance with the HON MACT requirements if that is the primary area of concern at a chemical manufacturing facility. If at some point later in the year, the regulatory agency decided a Full Compliance Evaluation was necessary, the agency could combine the results of the MACT evaluation with subsequent evaluations focusing on the balance of other CAA requirements.

Investigations

An Investigation can be distinguished from the other two categories in that generally it is limited to a portion of a facility, is more resource intensive, and involves a more in-depth assessment of a particular issue. It usually is based on information discovered during a Full Compliance Evaluation, or as the result of a targeted industry, regulatory or statutory use and analysis of information not available in EPA data systems. It is best used when addressing issues that are difficult to evaluate during a routine Full Compliance Evaluation because of time constraints, the type of preliminary fieldwork required, and/or the level of analytical expertise needed to determine compliance.

Examples of this category of compliance monitoring are the in-depth PSD/NSR and NSPS reviews conducted by EPA of the pulp, utility and petroleum refining industries. These investigations were initiated following analyses of publicly available information on growth within the industries, and a comparison of this information to data maintained by the regulatory agencies on the number of PSD/NSR permits issued during the same timeframe. The analyses indicated that many facilities failed to obtain the necessary permits. As a result, the facilities had not controlled pollutant emissions as required and thus realized significant economic benefits.

Compliance Plan Enforcement. The purpose of a compliance plan inspection is to inspect progress toward specific milestones of a compliance plan, administrative order, court order or Section 113(d) delayed compliance order. Many agencies will formalize administrative orders into negotiated compliance plans. Compliance plans may also be generated in cases brought before a hearing board or into a court of law. Once such plans are negotiated or directed, their implementation is subject to verification by onsite inspection.

The purpose of a compliance inspection is to inspect progress toward specific milestones of a compliance plan, administrative order, court order or delayed compliance order.

The most important parts of the compliance plan are the scheduled tasks and their completion dates, entered into the plan as recognizable milestones indicating progress toward the ultimate compliance status. The compliance plan should always include a specified penalty for failure to meet the various completion dates. A compliance plan for the construction or modification of a major facility would include the following milestones:

a. Engineering study, pilot studies and source testing to generate process and emission data, and cost estimates.

b. Approval of funds by management (Board of Directors).

c. Completion of final design, bids taken and best proposal selected.

d. Approval of APC Agency. Construction permit secured.

e. Order placed for equipment.

f. Delivery of equipment.

g. Installation and system start-up.

h. Source test for compliance.

i. Operating permit secured.

A well-monitored compliance plan materially benefits enforcement efforts because:

a. Time slippage can be spotted and action taken to increase the speed of the compliance program.

b. Valuable time is saved in generating legal compulsion if there is no action or gross deviation from the time schedule.

c. Penalties for noncompliance are apparent to the source.

A surveillance inspection is a systematic program of looking for observable violations within the inspector's assigned district.

Surveillance and Complaint Response. Surveillance is accomplished by a systematic program of looking for observable violations within the inspector's assigned district. Observations are made from outside the source boundary and are either on a random basis or according to a schedule by time or source class. Surveillance should be around-the-clock where conditions and agency personnel permit and should include unannounced onsite inspections.

Response to citizen complaint is a significant part of the inspector's job. A complaint can involve a specific violation such as visible emission, or it can and often does relate to nuisance.

Initiation of an Enforcement Action. Enforcement action must be taken whenever the inspector establishes the facts and gathers evidence to prove the occurrence of a violation of the rules and regulations, a permit to construct or operate, or the terms and conditions of an order or compliance plan.

The objective of enforcement is to bring all sources into a compliance status as soon as possible. Enforcement alternatives range from voluntary compliance on specific notice to comply to "file legal action first and talk later." Most agencies operate somewhere in between, depending on the circumstances of the violation, the agency resources, the specifics of the statutes, and the availability and effectiveness of legal assistance including the judicial processes of the area. Alternative enforcement procedures include:

a. Notice of violation with administrative orders to correct. Used for first offenders and for relatively new requirements.

b. Administrative conference or hearing leading to a formal administrative abatement order and an agreed-on compliance schedule.

c. Citations, which are paid without court appearance, similar to traffic tickets.

d. Administratively imposed penalties according to a schedule of fines.

e. Civil or criminal suits leading to imposition of fines and other punishments and/or judicial orders incorporating specific compliance plans.

f. Court ordered injunctions to stop the violating practice.

g. Administrative revoking of permits to construct or permits to operate, making further work or operation unlawful.

Alternative Enforcement Procedures

- *Notice of violation*
- *Formal abatement order*
- *Citations*
- *Administrative fine*
- *Civil or criminal punishment*
- *Court-ordered injunction*
- *Revocation of Operating Permit*

An agency's choices of enforcement action and notification methods are handed down to field personnel as a policy of enforcement. Only by having a clearly defined enforcement policy or an established set of enforcement procedures will inspectors working in the field have the guidance to react to like situations uniformly.

Steps in an Enforcement Action. There are five steps to an enforcement action:

a. The violation is found and documented in an inspection report.

b. Decision made by agency on the level and type of enforcement action to be initiated.

c. Enforcement documents drafted and filed. The inspector may be responsible for drafting all or a portion of a notice of noncompliance or a formal complaint or compliance order.

d. Settlement negotiations entered. The inspector may serve as a member of the team negotiating a settlement agreement with the violator; at a minimum the inspector is likely to be consulted.

e. Hearing or trial conducted. If the case is litigated, the inspector may find his notes and other documents subject to discovery, and ultimately may be called on to serve as a government witness.

The Goals of Enforcement. Enforcement actions are essentially those actions that are taken by an agency in response to violations of environmental law. The severity of the enforcement action is largely subjective and depends on the circumstances and seriousness of the violation. The U.S. EPA and state agencies generally use the following criteria or goals to select an appropriate enforcement action:

a. Correct the violation as quickly as possible. In many cases an environmental problem or threat has been created by a violation. It is the Agency's goal to resolve that problem or threat quickly.

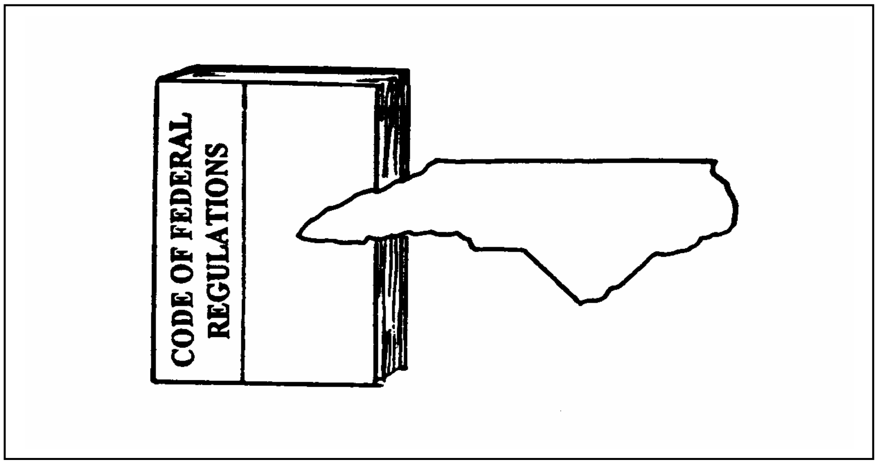
The severity of the enforcement action is largely subjective and depends on the circumstances and seriousness of the violation.

b. Deter future violations by the same party or by other parties.

c. Maintain consistency and fairness in assessing fines among similar violations.

d. Seek criminal sanctions against the most severe violators.

e. Make the most efficient use of enforcement resources to achieve human health and environmental goals.



Penalty Assessment Criteria

Except for some minor instances, courts and administrative law judges are required to consider identical penalty assessment factors for both stationary and mobile source violations in judicial or administrative proceedings and citizen suits. When assessing the penalty, the following factors must be considered: size of the business, economic effect of the penalty, compliance history of the company, duration of violation, previous penalties for same offense, economic benefit that the company receives for failing to comply, and the seriousness of the violation.

Penalty Factors

- *Size of business*
- *Economic effect of penalty*
- *Company compliance history*
- *Duration of violation*
- *Previous penalties for same offense*
- *Economic benefit for noncompliance*
- *Seriousness of violation*

Compliance Certification and Enhanced Monitoring

Section 114(a)(3), as revised by the 1990 CAA Amendments, requires major sources to submit annual compliance certificates, reports and enhanced monitoring. Annual compliance certifications should provide information concerning a source's noncompliance status. Congress intended these requirements to shift the burden of compliance assurance to the source. They are hoping this information will qualify as admissions and *prima facie* evidence of liability.

As result of Congress requiring “enhanced monitoring” of major sources, the EPA passed the “Compliance Assurance Monitoring” (CAM) Rule (62 Fed. Reg. 54900 (1997)). This Rule is intended to assure continuous compliance with CAA emission limitations through frequent monitoring of a facility’s control equipment (i.e., monitor specific indicators of a control device’s performance such as temperature, airflow, pressure, etc.) or any processes significant to achieving compliance. Performance specifications for CAM monitoring must assure that the data generated will “present valid and sufficient information on the actual conditions being monitored”. The CAM Rule is applicable to Title V major sources. These sources are responsible for developing the monitoring approach that it believes will satisfy the CAM requirements. Title V permitting authority shall review and approve the CAM plan. The effect of the CAM Rule is that evidence of liability can now be more easily obtained.

The “Any Credible Evidence” Rule allows EPA to site noncompliance by using any credible evidence such as CEM or other emissions records.

The Any Credible Evidence Rule

Under Section 113(e)(1) of the 1990 Amendments, Congress gave the EPA authority to use (in lieu of applicable test methods) “any credible evidence” to prove a violation. This removed restrictions that require strict proof of violations based on EPA-approved reference test methods by using “any credible evidence.” The EPA adopted regulations to implement these provisions (See: 62 Fed. Reg. 8314 (1997). These regulations are called the Any Credible Evidence Rule. This Rule will allow the use of any credible evidence for enforcement purposes. Prior to the Any Credible Evidence Rule, EPA *required* that a violation of an emission standard would have to be proved by using EPA reference test methods. Now, by using this Rule, noncompliance can be shown by using any credible evidence such as continuous emission monitoring data or other emissions records. The effect of this Rule is not only an asset to EPA enforcement, but greatly helps out citizen’s suits by making evidence of noncompliance more easily obtainable by using freedom of information acts.

Compliance Audits

In light of the expansion of criminal liability under the CAA, a company should consider conducting an internal environmental compliance audit. Although the company will have an affirmative duty to report violations of the CAA when it discovers them, voluntary disclosure and cooperation with EPA will mitigate and reduce an enforcement action. In 1995, EPA issued a notice that provided that it would seek lower civil penalties and not pursue criminal action where a company discovered, voluntarily reported, and promptly corrected violations pursuant to an audit program.

Also, numerous states now have adopted audit privilege laws. Typically, the audit privilege laws offer either a qualified evidentiary privilege or immunity (or reduction) from penalties for violations discovered during a compliance audit. Most privilege laws require that the company properly initiate corrective action.

Enforcement Responsibility

Section 101(a)(3) of the Clean Air Act states that the responsibility for the prevention and control of air pollution at its source primarily lies with state and local governments. While air pollution laws and regulations are monitored and enforced at all levels of government, the states and local agencies are usually those primarily responsible for the majority of compliance and enforcement actions. The U.S. EPA does not typically become involved until a state demonstrates a reluctance to enforce the provisions of its own control programs. The single most important tool and the fundamental source of state authority to enforce pollution control programs therefore are the State Implementation Plans (SIPs). Title 40, Part 51 of the Code of Federal Regulations (40 CFR 51) extends specific legal authority to the states to implement enforcement plans (U.S. CFR, 40 CRF 51).

The Clean Air Act places all responsibility for the enforcement of air pollution regulations on state and local governments.

States may ensure compliance through the use of many methods. For example, they can review new construction plans to determine that appropriate control technology is in place to meet compliance schedules. States are also authorized to gather information about sources of pollution through site inspections and emissions testing. Public law also provides that a source must maintain comprehensive records and submit regular reports that accurately quantify plant emissions. Finally, legislation has extended broad investigatory powers to the various states in order to detect violations and to inquire about public complaints regarding air pollution.

Although the U.S. EPA is the approving authority of all State Implementation Plans (SIPs), each state must ensure that every plan is equipped with a detailed enforcement component and that they maintain a sufficiently trained staff to investigate questions of compliance. In some cases, states may delegate its enforcement authority to local air pollution agencies. In California, for example, the South Coast Air Quality Management District holds authority for all air pollution control in and around the Los Angeles area.

Section 105 of the Clean Air Act allows the EPA to make financial grants to air pollution control agencies to implement air pollution control programs. This is a major source of funds utilized by states and local governments for operation of their air pollution programs.

NAME _____________________________________ DATE ______________SCORE________

CHAPTER 14 COMPLIANCE AND ENFORCEMENT

Multiple Choice

Directions: *Read each question and choose the best answer. Write the letter of your answer in the space provided.*

1. The goals of the enforcement process are all of the following, **except** _______.

a. correct the violation.
b. deter future violations.
c. determine compliance with national standards.
d. ensure equitable treatment of offenders.
e. achieve human health and environmental goals.

1.________

2. Air pollution laws and regulations are monitored and enforced at all levels, but those primarily responsible for compliance and enforcement actions is (are) the _______.

a. USEPA Office of Air Quality Planning and Standards (OAQPS)
b. National Center for Environmental Assessment (NCEA)
c. NRML Air Pollution Prevention and Control Division (APPCO)
d. Office of General Counsel (OGC)
e. States

2. _______

3. Which of the following is an enforcement methods or systems?

a. Permits to construct and operate.
b. Compliance monitoring.
c. Surveilance and complaint response.
d. Compliance plan enforcement.
e. All of the above

3. _______

4. Any agency action, whether formal or informal, intended to compel regulated sources to comply and to make them aware of the consequences of noncompliance are _______ activities.

a. compliance
b. deterrence
c. enforcement
d. measurement
e. monitoring

4. _______

Matching

Directions: *Match each of the following descriptions with the proper level of compliance inspection.*

Compliance Monitoring Categories

________	**5.**	Full Compliance Evaluation	a.	Focuses on a subset of regulated pollutants, emissions units or regulatory requirements.
________	**6.**	Partial Compliance Evaluation	b.	Generally limited to a portion of the facility, more resource intensive, and more in-depth on a particular issue.
________	**7.**	Investigation	c.	A comprehensive evaluation of a facility's compliance status (covers all facility's emission units and regulated pollutants).

REVIEW ANSWERS

No.	Answer	Location/ Page Number of Answer
1.	C	14-16
2.	E	14-18
3.	E	14-3
4.	C	14-3
5.	C	14-10 → 14-12
6.	A	
7.	B	

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