AIR POLLUTION CONTROL
Guidebook for Management

EDITED BY
A. T. ROSSANO, JR.

AIR POLLUTION CONTROL
Guidebook for Management

EDITED BY

A. T. ROSSANO, JR.

University of Washington

McGraw-Hill Book Company

New York St. Louis San Francisco Düsseldorf Johannesburg
Kuala Lumpur London Mexico Montreal New Delhi Panama
Paris São Paulo Singapore Sydney Tokyo Toronto

PREFACE

This text was written to serve as an introduction to the complex and burgeoning problem of community air pollution. The important basic principals of air pollution control have been approached in such a manner to enable both technical and non-technical persons to gain a working knowledge of the subject.

The book may also be used as a reference text in an introductory course in air pollution at the university, college or high school level. Individual chapters are written by recognized specialists in the various aspects of the air pollution field.

This book discusses the many diverse and interdisciplinary aspects of the subject including CHEMISTRY, ENGINEERING, METEOROLOGY, BIOLOGY, LAW and ADMINISTRATIVE.

The first half of the guidebook is devoted to a *description* and *evaluation* of the problem based on a simplistic system model approach. Such topics are discussed as the dynamics of air pollution meteorology, chemistry of air pollution, air monitoring, and the biological and social effects of air pollution.

The last half of the book concentrates on general as well as specific approaches to the *elimination* or *control* of air pollution. This section contains discussions of engineering control measures including theory, design and experience relative to particle and gas collectors such as cyclone collectors, filters, scrubbers, electrostatic precipitators, and furnace incinerators.

An entire chapter is devoted to the subject of source testing by stack sampling techniques. Another chapter is devoted to a discussion of several actual industrial pollution problems and how they were successfully handled.

The text concludes with discussions of the administrative and legal aspects of air pollution control including a critical review of several recent court cases.

In summary, the authors of this book have brought together the pertinent information on the chemistry and engineering of air pollution control in a compact definitive work. There are still many unanswered questions about effective air pollution control; however, this book does bring together a great deal of data and interpretations which truly justifies it as a Guidebook for Management.

CHAPTER 1

INTRODUCTION

I. Air Pollution Followed Water Pollution

It is axiomatic that the more advanced a civilization becomes, the more complex are the problems related to man's environment, namely, congestion, crime, housing, traffic, noise, etc. Of recent years, it has become increasingly obvious that the improper disposal of solid, liquid and gaseous wastes is creating a burgeoning problem of environmental pollution. The resulting alteration of man's natural environment has reached the point where the environment is now beginning to exert untoward effects on man.

Up until a few decades ago, public health and sanitary engineering authorities were concerned with contamination of water and food by bacteriological organisms, particularly those which inhabit the gastro-intestinal tract of man. With the gradual development and application of good sanitary engineering practices such as water filtration, chlorination and sewage treatment, the threat of outbreaks of water- and food-borne diseases has greatly diminished. However, as these biological contamination problems subside, a new variety of environmental pollution problems emerge. These are linked with chemical and physical agents. Radioactive isotopes and carcinogenic material are now of greater concern than the dreaded E. coli and E. typhosa of yesteryear. Moreover, the spotlight is turning more and more from water and food to the atmosphere as a vector of disease. Public health authorities are now not only concerned with the prevention of water- and food-borne typhoid, cholera and dysentery, but also with asthma, emphysema and chronic bronchitis, which are air-borne diseases.

About fifty years ago, the rivers and lakes of this country began to show signs of deterioration from human and industrial wastes. The pollution eventually became so intense that drastic action had to be taken to protect human health and well-being. By means of effective sanitary engineering measures, including waste treatment and water purification, it was possible to meet the needs of an expanding population without serious incidents. While water was no longer "free", it was, nevertheless, safe.

Within the past twenty years, we have witnessed a parallel development in the field of air resources. There is scarcely an urban area in the United States or in the entire world, where air pollution, in some degree of severity, is not clearly manifest. Impressive expenditures by government, industry and the general public now make quite inappropriate the old cliche – "Free as the Air".

II. Historical

Historically, air pollution is not a new phenomenon. Natural forms of air pollution, such as volcanic eruptions, were known and feared by prehistoric

man. The emission of massive quantities of fine dust, cinders and toxic gases during the eruption of Mt. Vesuvius outside of Naples, Italy in 79 A.D., was recorded by Tacitus, the Roman historian. In letters to him, Pliny the Younger related how his uncle, Pliny the Elder, died, presumably from exposure to sulfurous gases.

Man-made pollution probably dates back to the early cave man who discovered fire. Having discovered this as an invaluable source of energy for keeping warm and cooking food, from time to time he undoubtedly was forced to flee from his cave coughing and choking from the noxious smoke and gases from his primitive fire.

Many other historical references to air pollution can be found in Roman and English history. The introduction of so-called "sea-coals" in 13th Century England gave rise to mounting complaints of the nuisance from smoke and gases. This gave rise to the first smoke control regulations which at times were so strictly enforced that the death penalty was evoked.

John Evelyn, the famous English naturalist, was so provoked by the severe air pollution in London that in 1661 he wrote his now famous paper entitled, "Fumifugium, or, the Inconvenience of the Aer and Smoak of London Dissipated". In this remarkable treatise, he not only described the nature and sources of air pollution in London, but also recommended control measures, such as relocation of offending industries in remote areas, and planting of trees and shrubs to form green belts.

The smoke and flyash problem continued to worsen in various parts of England, especially during the Industrial Revolution which had its birth in that country in the late 18th Century, largely because of its abundance of coal. Several severe air pollution episodes occurred in 19th Century London. Though many persons lost their lives during these incidents, they were not recognized as disasters at that time.

In the early nineteen hundreds, Dr. Des Voeux, an English physician, coined the term "smog" to describe the offensive combination of smoke and fog which he concluded was the cause of respiratory distress among his patients.

As London grew larger, the smog problem worsened until 1952, when a very severe episode resulted in the death of 4000 persons and an untold number of illnesses.

A recurrence in 1962 took a much lower toll of lives presumably, in part, because of smog control measures which had been instituted as a result of the earlier disaster.

In the United States, the problem of smoke was manifest during the early history of the developing industrial centers of the East and Midwest. St. Louis and Cincinnati were among the first cities in this country to adopt smoke abatement programs. The widespread adoption of smoke prevention regulations and improved fuel burning technology and equipment gradually brought the problem under a tolerable degree of control.

As the national economy slowly switched from coal to petroleum as a major

source of energy conversion, the quality of the atmospheric environment took a turn for the worse. While the smoke pollution problem was subsiding, a new and perhaps worse form of air pollution began to emerge. Instead of smoke, soot and flyash, this new species of pollution was characterized by such exotic substances as oxidants, peroxides, ozonides and various hydrocarbon reaction products. This form of air pollution was first encountered in Los Angeles in the early 1940s and has gradually worsened in spite of heroic control efforts.

In many ways, this new type of smog, more correctly referred to as photochemical air pollution, is worse than the old problem of coal smoke in that it is not thoroughly understood, is more difficult to control, and has graver public health implications because of its widespread distribution throughout the populated areas of this country.

III. Factors Responsible for the Burgeoning Air Pollution Problem

While, as mentioned previously, air pollution is not a new phenomenon, it is now apparent that it is one of our most rapidly growing environmental problems. What are the factors contributing to this rather recent trend toward deterioration of the air environment? There are three major underlying factors which serve to explain this condition:

A. Population Growth

The upward trends in population growth in the United States, since World War II, have indeed been impressive. More people mean more manufactured goods and services. This, in turn, leads to the second factor.

B. Expansion in Industry and Technology

The growth of industrial activity, in the same period, has likewise been remarkable in terms of expansion of existing plant capacity, and the increase in number of new manufacturing establishments. In addition, there has been the introduction of a great number of new processes, methods and products. The nature of the airborne wastes from some of these new technologies was completely unknown until adverse effects on man and his environment suddenly became manifest. New industries and processes introduced on a large scale within recent decades include oxygen lancing in steel production, catalytic cracking of petroleum products, manufacture of copolymers, and nuclear energy. In most cases, the raw materials and by-product wastes initially were of unknown toxicity, and knowledge of the methods and procedures for abatement of resulting pollution problems lagged far behind the technology of manufacture. The combination of increasing quantities of atmospheric emissions, including materials of undefined character, compounded the growth and complexity of atmospheric pollution.

C. Social Changes

Two important social changes occurred during this same period, and

served to accelerate the trend of burgeoning air pollution:

1. Urbanization

The unrelenting movement of people from rural sections into urban centers has led to the rapid evolution of cities into large metropolitan complexes. On the East Coast, the expansion of the metropolitan areas of Boston, New York, Philadelphia, Baltimore and Washington, D.C. has resulted in the virtual fusion of the entire region into one large megalopolis. There are no longer the open and sparsely populated spaces between these cities that existed twenty or more years ago. Within a few years, over three-fourths of the nation's population will reside in about 1% of the land area. The result of this development is an ever increasing areal density of population and of industrial and commercial activity. Thus, the producers of airborne pollutants now, more than ever before, reside in close proximity to the potential receptors. Such a juxtaposition greatly increases the frequency and severity of interactions between the two, and makes the goal of acceptable air environment extremely difficult to attain.

2. The other social factor which has indirectly contributed to the intensification of air pollution over relatively recent years has been the rising standard of living which has prevailed during this period. Large segments of the population have been economically able to enjoy a better life, including higher quality of nutrition, housing, transportation, and a variety of labor-saving devices. Few families today are without a car, television set, refrigeration, automatic washing machines and clothes dryer, etc. The vast majority of these conveniences require electric power and this, in part, accounts for the fact that the demand for electric power in the United States doubles every ten years. Most of this power is generated by thermal power plants burning coal or oil. Since the combustion of these fuels produces large volumes of contaminant emissions, the potential for air pollution from this source is rapidly increasing.

The motor vehicle, on which practically every American family is highly dependent, likewise is another major source of pollutants, which are emitted largely from the internal combustion engine.

Modern society produces greater per capita solid refuse than ever before. Greater use of paper, plastic and similar materials for single service containers, and for packaging food and numerous domestic and commercial products of everyday life is placing enormous demands on solid waste disposal facilities. Open burning and incinerators of all types and sizes are emitting air-contaminating combustion products of increasing quantities and chemical complexity.

Thus, the ability of the general population to afford more comforts,

conveniences, and labor- and time-saving machinery, contributes very significantly to air pollution originating from the energy conversion processes which provide the necessary power. Thus, a more affluent and educated society demands a better quality of environment than this country has ever enjoyed, while unsuspectingly contributing indirectly to the very environmental degradation they abhor.

The combined impact of population growth, expansion in industry and technology and social changes operating in our contemporary society can be regarded as the compounding factors which have resulted in serious degradation of the urban air environment within relatively recent years. In certain metropolitan areas such as New York, Los Angeles, Philadelphia, Chicago and St. Louis, this trend has already reached alarming proportions. In those areas, the rate of pollution very frequently exceeds the capacity of the atmosphere to purify itself by natural processes of dilution and dispersion. During these periods, severe air pollution occurs and is clearly manifested by eye irritation, reduced visibility and other adverse effects.

IV. Air Pollution Defined

In its broadest context, air pollution can exist in three distinct categories:

1. Personal Air Pollution – This refers to exposure to dust, fumes and gases to which an individual exposes himself when he indulges in cigarette, cigar or pipe smoking. While the potential hazards from this form of pollution are considered by many authorities to be serious, the solution to the problem technically is relatively simple – give up smoking!

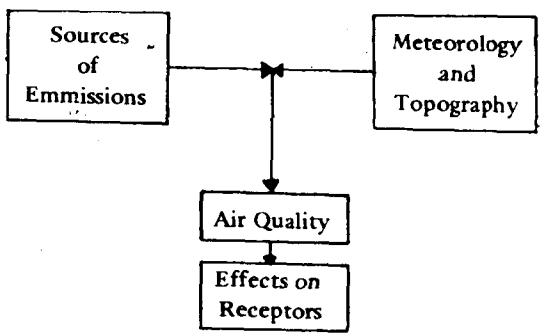
2. Occupational Air Pollution – This represents the type of exposure of individuals to potentially harmful concentrations of aerosols, vapors and gases in their working environment. Such exposures are frequently very serious, and the problem of occupational diseases has been recognized from ancient times up to today's modern technological civilization. These problems fall within the province of industrial hygiene.

3. Community Air Pollution – In this course, we shall be concerned primarily with this type of air pollution. It represents the most complex of the three varieties since it involves a varied assortment of pollution sources and contaminants, meteorologic factors, and a wide diversity of adverse social, economic and health effects. Not only does community air pollution affect many more individuals because of the pervasive nature of the atmosphere, but it can also exert a significant impact on man's total environment, including plants, animals, property and the weather itself. Unquestionably, it is the most difficult variety of air pollution to evaluate and control.

In its policy statement on "Air Pollution and Its Control", proposed by its Air Pollution Committee (Report Number 107), the Engineers Joint Council provides us with an excellent definition of the term "air pollution", which we

shall adopt for the purpose of this course: "Air Pollution means the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odor, smoke or vapor, in quantities, of characteristics, and of duration such as to be injurious to human, plant or animal life or to property, or which unreasonably interferes with the comfortable enjoyment of life and property."

Upon closer examination of some of the underlying facts concerning the nature, causes and effects of community air pollution, it becomes increasingly obvious that it represents a most complex environmental phenomenon. Moreover, air pollution, as we know from personal experience, is a constantly changing condition. Skies laden with heavy air pollution can be quickly transformed to clear, blue skies within hours by a sudden change in the weather, such as results from the passage of a weather front. It is obvious, therefore, that we are dealing with a dynamic problem. As complex as the phenomenon may be, it can be easily and graphically depicted by means of a simplified systems analysis approach. Figure 1 represents such a systems diagram.



It can be inferred that the mere presence of sources of emissions does not necessarily constitute air pollution. However, it is possible for unfavorable meteorological factors to interact with the emission factor to create undesirable air quality. If the quality of the air deteriorates sufficiently, the atmospheric environment begins to exert adverse effects on man and his possessions. The degree of inconvenience, damage or illness produced depends upon the particular receptor involved and the degree of exposure.

Throughout the remainder of this course, we shall systematically describe in considerable detail each of the factors depicted in the systems flow diagram. The course will conclude with discussions of air pollution control and prevention on the basis of specific technological control systems, as well as broad resource management concepts.

A. T. Rossano, Jr., Sc.D.

CHAPTER 2

SOURCES OF AIR POLLUTION

I. General Classification of Sources

A. Important Factors

In evaluating the role and importance of emissions in air pollution, several factors must be considered, as follows:

1. Type of source – This refers to considerations of natural and man-made sources, as well as to broad classifications and specific examples within each class. The source factor will be discussed in greater detail below.

2. Number and spatial distribution of sources – Air pollution sources can be grouped in three major categories:

a) Single or point sources. These are the rather large readily identifiable sources as a power plant, petroleum refinery, and steel mill.

b) Area-wide or multiple sources. These represent collectively, a large number of smaller sources distributed over a well-defined area. Examples of this are an entire residential area, or a block of apartments or commercial buildings concentrated in one section of the community.

c) Line sources. Freeways, highways and arterials carrying a steady stream of moving vehicles contribute line sources of pollution.

3. Type of emissions – Of most direct importance to the problem of air pollution are the nature and characteristics of the contaminants emitted to the atmosphere. For convenience, all emissions can be segregated into the three traditional states – solid, liquid and gaseous. The following table lists some of the more common types of contaminants grouped into two major divisions – Particulate and Gaseous. The former is further subdivided into solid and liquid particulates. The accompanying list of selected terms provides specific technical definition of these types of contaminants.

Classification of Airborne Contaminants

Particulate Matter		Gaseous Substances
Dust	Droplets	Gases
Flyash	Mist	Vapors
Smoke	Fog	
Soot	Fumes	
Aerosol Particles		

Examples of Airborne Contaminants

Dust	Fumes	Droplets or Mist	Gases	Vapors
Cement	Iron Oxide	Sulfuric Acid	Sulfur Dioxide	Gasoline
Coal	Zinc Oxide	Chromic Acid	Nitrogen Oxide	Trichlor-ethylene
Ores	Lead Oxide	Oil	Carbon Monoxide	Perchlor-ethylene
Grains		Grease (from cooking and smoking of meats)	Hydrogen Sulfide	Toluene
Rock Sawdust		Paint	Chlorine	Styrene

DEFINITIONS OF SELECTED AIR POLLUTION TERMS

Aerosol – A dispersion of solid or liquid particles of microscopic size in gaseous media, such as smoke, fog or mist.

Dust – A loose term applied to solid particles predominantly larger than colloidal and capable of temporary suspension in air or other gases. Dusts do not tend to flocculate except under electrostatic forces; they do not diffuse but settle under the influence of gravity. Derivation from larger masses through the application of physical force is usually implied.

Droplet – A small liquid particle of such size and density as to fall under still conditions but which may remain suspended under turbulent conditions.

Fly Ash – The finely divided particles of ash entrained in flue gases arising from the combustion of fuel. The particles of ash may contain incompletely burned fuel. The term has been applied predominantly to the gas-borne ash from boilers with spreader stoker, underfeed stoker, and pulverized fuel (coal) firing.

Fog – A loose term applied to visible aerosols in which the dispersed phase is liquid. Formation by condensation is usually implied. In meteorology, a dispersion of water or ice.

Fume – Properly, the solid particles generated by condensation from the gaseous state, generally after volatilization from melted substances, and often accompanied by a chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce. Popularly, the term is used in reference to any or all types

Characteristic properties of the various airborne contaminants are important in considering their potential role in air pollution. Among these are:

a. Physical Properties:

Particle size, shape, surface area, density, electric charge, radioactivity. In addition, vapor pressure, temperature and pressure of gaseous substances are important properties, particularly as they may relate to their state while in storage or in stacks.

b. Chemical Properties:

Acidity and alkalinity, solubility, hygroscopicity, photochemical reactivity of vapors and corrosiveness.

c. Biological Properties:

Toxicity to human, plant and animal tissue; taste, odor.

---

of contaminants, and in many laws or regulations, with the added qualification that the contaminant have some unwanted action.

Gas – One of the three states of aggregation of matter, having neither independent shape nor volume and tending to expand indefinitely.

Mist – A loose term applied to dispersions of liquid particles, the dispersion being of low concentration and the particles of large size. In meteorology, a light dispersion of water droplets of sufficient size to be falling.

Particle – A small discrete mass of solid or liquid matter.

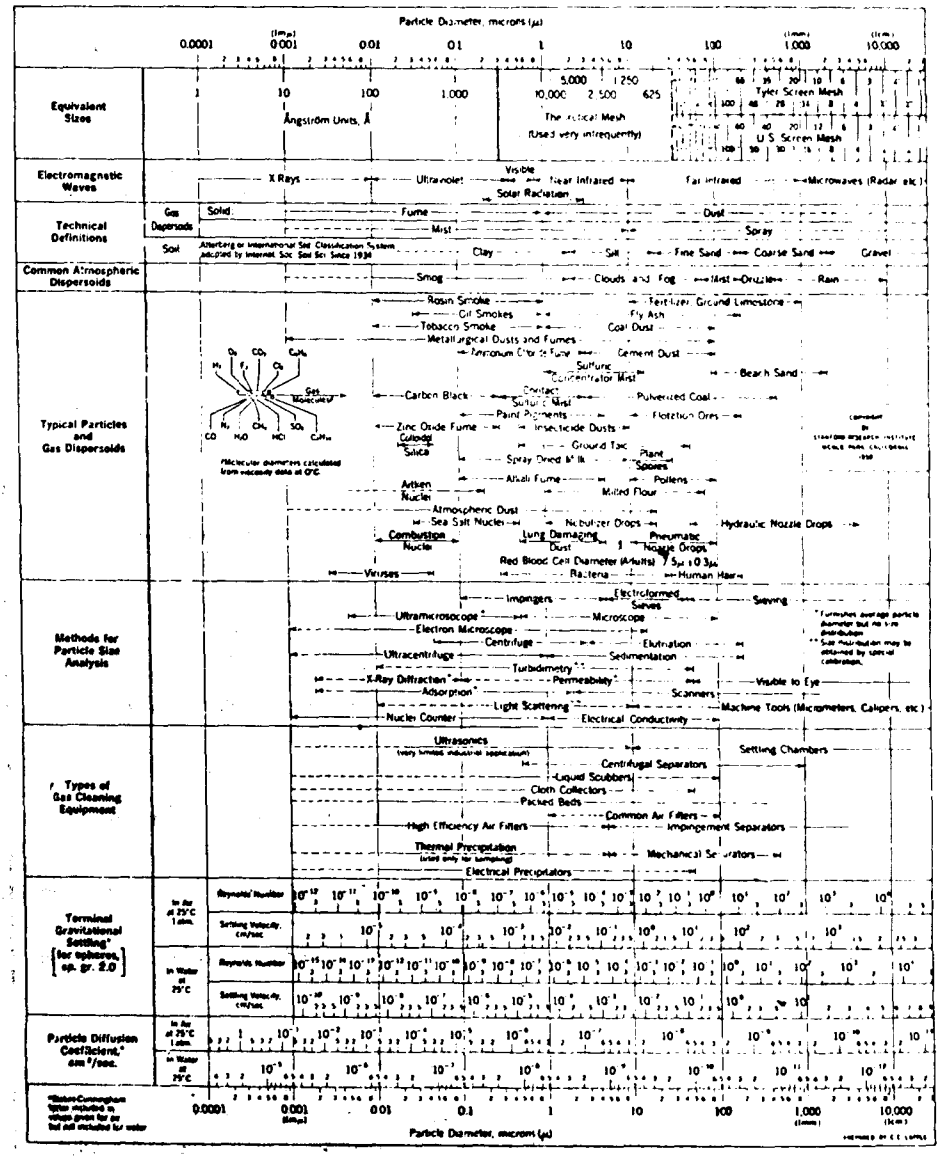
Smoke – Finely divided aerosol particles resulting from incomplete combustion. Consist mainly of carbon and other combustible material.

Soot – Agglomerations of particles of carbon impregnated with "tar", formed in the incomplete combustion of carbonaceous material.

Vapor – The gaseous phase of matter which normally exists in a liquid or solid state.

Reference: American Society for Testing and Materials, Standards on Methods of Atmospheric Sampling and Analysis, Committee D-22, Philadelphia 3, Pa., Oct. 1962.

CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSOIDS



4. Rate of Contaminant Emission

Air pollution is a manifestation of a condition in which the rate of introduction of foreign substances into the ambient air exceeds the self-purification capability of the atmosphere. Thus, consideration of emission rates is germane to the entire problem. Units of expression in the field of air pollution are most unconventional and represent outgrowths from a number of professional fields and disciplines which have been historically involved. Some of these units are listed below:

Emission Units

Weight Basis	Concentration Basis
Pounds per hour	Parts per million (by volume)
Tons per day	Grains per standard cubic foot of dry gas
Pounds per pound of fuel (Ex.: Pounds of SO_2 per pound of coal)	Pounds per 1000 pounds of flue gas
Pounds per pound of finished product (Ex.: Grains of Fluorine per ton of Phosphate fertilizer)	

B. Natural Versus Man-Made Sources

Let us now return to a consideration of the classification of air pollution sources:

Natural Air Pollution Sources

Wind blown dust
Pollen and other aero-allergens
Sea salt nuclei
Smoke, flyash and gases from forest fires
Microorganisms
Gases and odors from swamps and marshes
Fog
Volcanic ash and gases
Natural radioactivity
Ozone from lightning and ozonisphere
Meteoritic dust
Natural Hazes (Blue Ridge and Smoky Mountains)

Man-Made Sources

The sources of man-made pollution cover a wide spectrum of types. The accompanying table includes a classification of major types, categories and examples of air pollution sources and their characteristic pollutant emissions.

Classification of Air Pollution Sources and Emissions

Source Type	Category	Examples	Pollutants
Dust Producing Processes	Crushing, grinding, screening	Road mix plants	Mineral and organic particulates
	Demolition	Urban renewal	
	Milling	Grain elevators	
Combustion	Fuel burning	Home heating units and power plants	Oxides of sulfur, oxides of nitrogen, carbon monoxide, smoke, flyash, organic vapors, metal oxide particles, and odors
	Motor vehicles	Autos, buses and trucks	
	Refuse burning	Community and apartment house incinerators, open burning dumps	
Manufacturing Processes	Metallurgical plants	Smelters, steel mills, aluminum refineries	Metal fumes (lead, arsenic, and zinc), fluorides and oxides of sulfur
	Chemical plants	Petroleum refineries, pulp mills, super phosphate fertilizer plants, cement mills	Hydrogen sulfide, oxides of sulfur, fluorides, organic vapors, particles, odors
	Waste recovery	Metal scrap yards, auto body burning, rendering plants	Smoke, soot, organic vapors, odors
Agricultural Activities	Crop spraying and dusting	Pest and weed control	Organic phosphates, chlorinated hydrocarbons, arsenic, lead
	Field burning	Stubble and slash burning	Smoke, flyash and soot
	Frost damage control	Smudge pots	

Classification of Air Pollution Sources and Emissions (Cont'd.)

Source Type	Category	Examples	Pollutants
Solvent	Spray painting	Automobile assembly, furniture and appliances finishing	Hydrocarbons and other organic vapors
	Inks	Photogravure and printing	
	Solvent cleaning	Dry cleaning, degreasing	
Nuclear Energy Activities	Ore preparation	Crushing, grinding and screening	Uranium and beryllium dust
	Fuel fabrication	Gaseous diffusion	Fluoride
	Nuclear fission	Nuclear reactors	Argon-41
	Spent fuel processing	Chemical separation	Iodine-131
	Nuclear device testing	Atmospheric explosions	Radioactive fallout (Strontium-90, Cesium-137, Carbon-14)

II. The Emission Inventory

Knowledge of the types and rates of emissions is fundamental to any study of community air pollution. There are several ways in which source information can be extremely useful. It can be of help in designing the air sampling and air analysis programs, and interpreting the resulting air quality data. It provides an explanation for observable adverse effects, and indicates the relative contribution of the various major pollution sources. In the establishment of a new abatement program, source data can serve as a basis for the development of ordinances and regulations while, in existing control programs, current emission data provides guidelines for modifications in engineering and legal control measures.

From the research standpoint, detailed emission data are necessary for constructing mathematical models of the atmosphere for purposes of predicting future concentrations of specific pollutants. The establishment of emission standards and planning and zoning regulations is greatly enhanced by the availability of current and predicted source information.

It must be stressed that, while knowledge of emission sources is fundamental to an understanding of the nature, causes and effects of air pollution in a community, air pollution source information *per se* is definitely limited in its

value. In other words, data on quantities of a pollutant emitted in one area are not necessarily directly relatable to the situation in another area. For instance, a given emission rate of a gas may be responsible for a serious problem in a specific location. The same emission rate applied to another area with differing meteorological, topographic, social and economic conditions may produce only a barely perceptible effect.

The systematic collection and collation of detailed information concerning the air pollution emissions in a given area are referred to as an emission inventory. To be of greatest use, such an inventory should contain as much information as possible on the types of sources as well as their contributions in terms of the composition and rates of discharge of the individual pollutants. This should be supplemented by information on the number and geographical distribution of sources, description of process, raw materials, and control measures.

The choice of units of expression in an emission inventory is immaterial as long as the system is consistent, realistic, and can be correlated with the particular air pollution condition or effect in question. Emissions are commonly reported in terms of weight of pollutant per unit of time.

Such an inventory should be kept current not only so that the effectiveness of the local control program can be periodically evaluated, and if necessary modified, but also because of the changing character of pollution sources in a rapidly expanding technological society.

While the inventory covers the entire region under study, attention must be paid also to sources and emissions which are not within the area, but which may contribute significantly to the air quality in the study area. While principal effort is directed at man-made sources, the contribution of relevant natural sources must also be taken into account.

A convenient classification of source types is as follows:

Class I. Fuel-Burning for Heat and Power Production

This includes the operating of heating equipment utilizing coal, oil, gas and wood for power production, space heating, and hot water. Included in this category are the following sources.

A. Utilities. These are the large steam-electric generating plants, both public and private.

B. Residences. These include single and multiple dwellings such as private homes, duplexes, and apartment houses.

C. Industrial Establishments. This category includes:

1. Manufacturing, both light and heavy, in accordance with the Standard Industrial Classification scheme of the U. S. Dept. of Commerce.

2. Commercial establishments such as stores, hotels, clubs, hospitals, and offices.

3. Processing, including laundries, dry cleaners, garages, and service stations.