Symposium on Detection and Measurement of Primary and Secondary Airborne Particulates and Their Effects on Plants

Introduction

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The interest of plant pathologists in the phytotoxic potential of atmospheric contamination generally has been focussed upon the effects on plants of the gaseous substances contributed to the atmosphere from anthropogenic sources. However, the air around us also abounds with a multitude of suspended particulates which, if less than a given size, may be distributed within air masses in much the same manner as its gaseous constituents. Previously it was believed that most of these substances were removed from the atmosphere within a short radius from their site of emission. Recent investigations have shown that gases, particles, and aerosols may undergo complex mixing, interaction, and transformation and that they and the resulting products can be dispersed to areas far removed from their points of origin. In this context, particles and aerosols are assuming an increasingly critical role in the over-all atmospheric pollution syndrome. Yet, there has been relatively little research in this field with respect to effects on vegetation. With a view to furthering an understanding of the impact of these atmospheric components, and on behalf of the Pollution Effects on Plants Committee of the American Phytopathological Society, I would like to welcome you to this Symposium which is titled "The Detection and Measurement of Primary and Secondary Airborne Particulates and Their Effects on Plants."

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Symposium on Particulates

The Origins and Influence of Airborne Particles

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The atmosphere is a heterogeneous mixture of gases and suspended solid material, the latter usually are classed as particulates. On a volume basis, these particulates are only trace constituents; their roles in the chemical and physical processes within the atmosphere, however, are critical.

Particulate matter within the atmosphere is ubiquitous. Significant concentrations are found over deserts, oceans, and forest land, as well as in densely populated urban and industrial areas. Much of the atmospheric particulate loading has a natural origin; eg, windblown dust, seasalt, and volcanoes. Emissions of man-made particulates from sources such as combustion systems and industrial processes, however, have increased and now detrimentally affect atmospheric properties.

Particulates control visibility within the atmosphere because of the critical role they play in scattering sunlight. They are an active agent in much of the plant damage associated with air pollution. They are a major factor in the corrosion of building materials and their role in causing and aggravating pulmonary diseases has been recognized for many years.

Air pollution standards for particulates.—Particulates were one of the first class of substances to be regulated by air pollution control legislation. The current standard for particulates is 75 $\mu g/m^3$ (~75 ppb, w/w in dry air) as an annual average for a given air pollution control district. In addition, for any 24-hr period, a concentration of 260 $\mu g/m^3$ was established as a maximum tolerable limit.

To achieve these standards, limits were set on the amount of solid material that could be discharged from various industrial smokestacks or automobile exhausts. Standards also were established for emissions of the gases SO_2, NO_2, O_3, CO, and hydrocarbons; these individually can cause adverse effects, but also are of interest here because they contribute to the formation of particulates in the atmosphere.

In many urban areas, the air quality standards for suspended particulate matter are not being met, and there are those who think that the procedures for attaining these standards may be inadequate. On the other hand, some scientists are questioning whether the established standards are a realistic goal. There is some evidence that in many cases natural and uncontrollable sources of particulate matter contribute enough to atmospheric loading to make the present standards unattainable. The situation is further complicated by the possibility of long-range transport of airborne particulates. An increasing body of data indicates that particulate matter (or gases leading to the formation of particulate matter) injected into the atmosphere in one location, can be deposited at other locations up to several hundred kilometers away. The implication is obvious: in some regions where deposition or fallout occurs, local enforcement of strict pollution control procedures will have little impact on air quality. The debate over standards for airborne particulate matter probably will intensify in the next few years, especially as the United States' energy needs are met by increased consumption of coal.

Coal combustion is a major source of particulate emissions as well as sulfur and nitrogen oxides which eventually form airborne particulates.

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Origins of airborne particulates.—Global particulate emissions have been estimated at 23.49 × 10^6 tonnes (26 × 10^6 short tons per year [8]). The distribution between natural and man-made sources is summarized in Fig. 1. These data are based on gross averages and are probably accurate to within a factor of five or so. Sea salt predominates because so much of the earth's surface is covered with water. For the most part, its influence on air quality is relatively minor. In fact, the influence of particulate mass-loading in general must be assessed cautiously since there is often little correlation between aerosol mass and air quality in general. The natural cycle of movement of most salt particles is completed with little or no impact on population centers. Emissions from man-made sources on the other hand often are localized near cities and have a significant impact upon building materials and the health of individuals in human and other biological populations.

Sources of man-made particulates within the United States are summarized in Fig. 2. In descending order of mass emission, fuel combustion is the predominant source, followed closely by stone-crushing operations. Other significant sources are agriculture, iron and steel, and cement-making. Other sources which contribute less than 5% each of the total emissions include the chemical process industries.

Primary and secondary particulates.—Particulates often are classified as primary or secondary. Primary particulates (usually about 1–20 μm in size) are those injected directly into the atmosphere by various industrial or combustion processes. Atmospheric particles ranging from 1.0 to 100 μm in diameter tend to have characteristics in common with local soil conditions or effluents from local industries. In maritime areas, airborne sea salt is in this size range. Industries that utilize grinding operations such as grain elevators, feed mills, cement factories, and ore-processing produce particles of this size. The size ranges of some common types of primary particles are shown in Fig. 3.

It is very difficult to create particles smaller than a few microns in diameter by pulverizing or grinding larger particles. The limiting factor is the large amount of energy required to provide the additional surface area that accompanies an increase in the number of smaller particles. Thus, small particles are produced almost exclusively in high-energy systems such as combustion engines and metal processing furnaces.

Secondary particulates are the products of certain reactions that occur in the atmosphere. These reactions can be initiated in the gas phase or can result from interactions between gases and airborne particles. Secondary particles range in size from molecular clusters having diameters on the order of 0.005 μm to particles with diameters as large as several micrometers. Field studies of several urban aerosols have shown that the majority of secondary particulates usually are in the range 0.01 to 1.0 μm. (1,3,12).

The main requirements for the formation of secondary particulates are sunlight and chemicals such as SO_2, NH_3, NO_3, water and hydrocarbons which enter the atmosphere from both natural and man-made sources. In general secondary particulates are composed of three types of compounds: sulfates, nitrates, and hydrocarbons. Figure 4 summarizes some of the formation mechanisms involved in secondary particulate generation.

A comprehensive summary of both the chemical composition and the physical size distribution of particles from potential sources of particulate emissions has not yet been compiled. Resolution of particles smaller than several microns is not included in most of the available data because early control strategies were based mainly on mass-loading and ignored the potential hazards of light-weight fine particles. Another interesting aspect of the composition of particulate matter is shown by very recent data which indicate that atmospheric aerosols have a bimodal size distribution as shown schematically in Fig. 5.

Recent experiments indicate that the bimodal size distribution tends to reflect their different particle formation mechanisms. The larger primary particulates are formed by a variety of physical and chemical means; they include soil dust and solid industrial emissions released directly into the air. The smaller secondary particulates are the product of chemical reactions taking place in the atmosphere. Information about chemical concentrations could have important environmental consequences, for the smaller a particle, the longer its atmospheric residence time. Smaller particles also are deposited very effectively in human lungs.

Health effects of airborne particulates.—Some of the ill effects of particulate matter on human health are obvious and annoying as anyone with an allergy or hay fever will confirm. At times, however, the effects of particulate matter in the air can be deadly. Usually the most serious threats to health result from a combination of heavy concentrations of particulate matter from industrial sources and

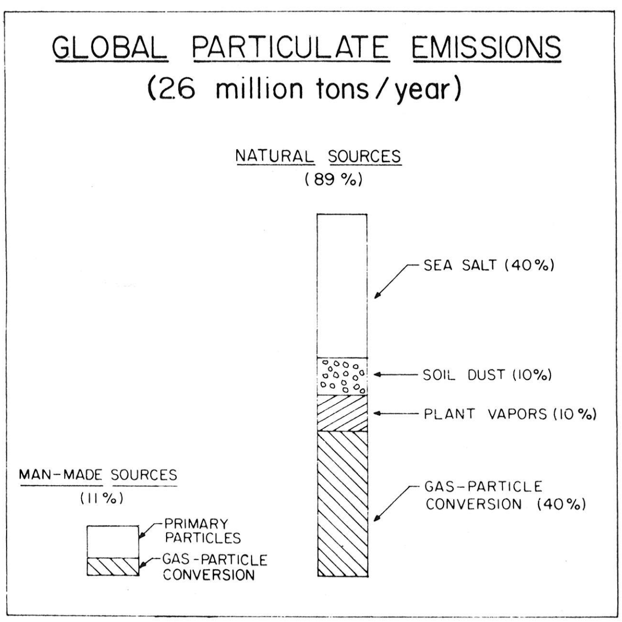

Fig. 1. Distribution of global airborne particulate emissions. (8)

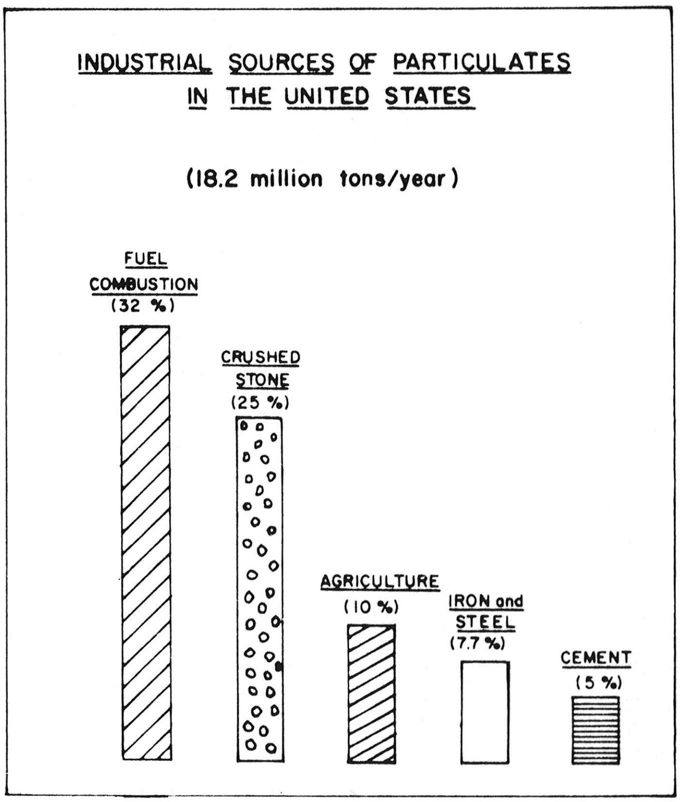

Fig. 2. Distribution of airborne particulate emissions among various industrial categories. (6)

weather conditions that prevent adequate mixing. It is estimated that 3,500 to 4,000 people died as a result of the severe fog of 5–9 December 1952 in London (5). The diseases for which mortality figures are quoted in the records of that incident are bronchitis, coronary diseases, myocardial degeneration, pneumonia, vascular lesions of the central nervous system, respiratory tuberculosis, and cancer of the lung. Other tragic air pollution episodes occured in the Meuse River Valley in Belgium in December 1930 (60 people died and 6,000 became seriously ill); in Donora, Pennsylvania, in 1948; and again in London in 1962.

The long-term effects of air pollution, and especially of airborne particulates, may be even more insidious. Specifying exactly which pollutants most significantly affect human health is difficult, little definitive information is available, and expanded research is needed. The time required for compiling accurate data has limited assessment of these long-term effects, but some advances have been made. In many epidemiological studies, for example, particulates have been shown to have a significant effect. Growing evidence indicates a consistent relationship between exposure to particulates combined with SO_2 and impaired ventilatory function in children 5–13 years of age (10). In Japan, the incidence of chronic bronchitis, bronchial asthma, and pulmonary edema has been linked to sulfuric acid mist and suspended dust particles (2). The effects of suspended sulfates on human health also have been examined by Shy and Finklea (9) who indicated that these particles contribute substantially to the aggravation of chronic respiratory disease.

Although it is not yet possible to identify the actual disease-producing mechanisms or even to know which specific types of particulates are involved, there is a growing concensus that fine particulates (ie, those smaller than several micrometers in diameter) are the primary suspects. These species are especially troublesome because they bypass the body's respiratory filters and penetrate deep into the lungs. More than 30% of the particles smaller than 1 μm that penetrate the pulmonary system remain there (7,11). The ability of fine particulates to become embedded in the tissue is a function primarily of their geometry and is independent of their chemical composition. Once the particles have been deposited, however, their chemical nature is a prime determinant of their toxicity. As noted above, growing evidence suggests that poisonous elements, especially heavy metals such as lead, cadmium, vanadium, and nickel, tend to be concentrated in these smallest particles, but even materials such as silicas, which for the most part are chemically inert, can cause acute physical irritation of sensitive lung tissue and lead to diseases such as silicosis. Particulates deposited in the lungs also can impair oxygen transfer, and, because they have fairly long lives in the atmosphere and are capable of absorbing significant quantities of toxic gases such as SO_2 and HCl, they can produce severe synergistic effects if inhaled.

In an extensive review of the literature, Lave and Seskin (4) attempted the difficult task of estimating the human health costs of air pollution. They found significant correlations of respiratory disease, cardiovascular disease, and cancer with air pollution indices (eg, dustfall, sulfation rate, concentration of suspended

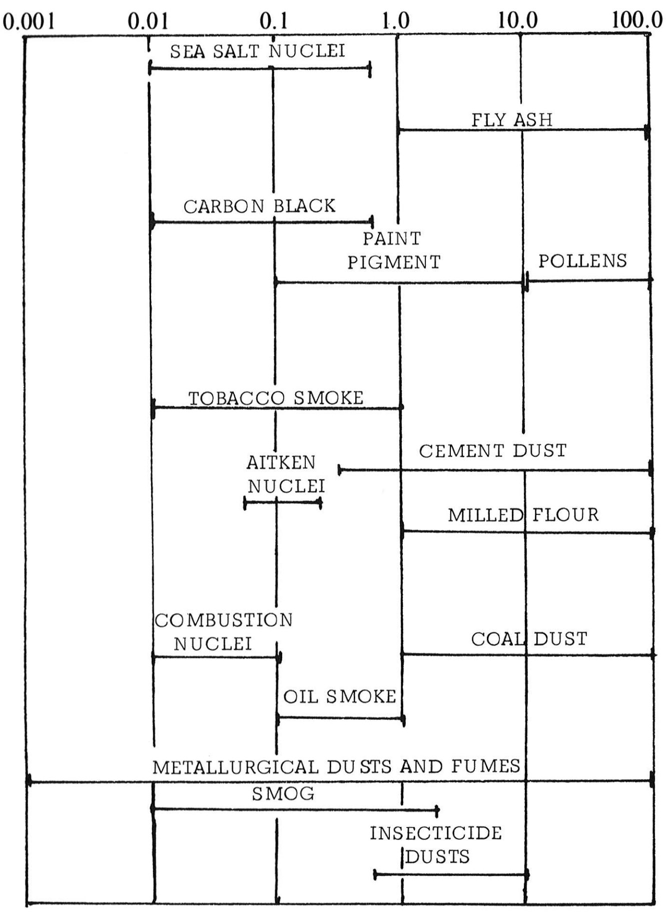

Fig. 3. Size distribution of commonly occurring airborne particulates.

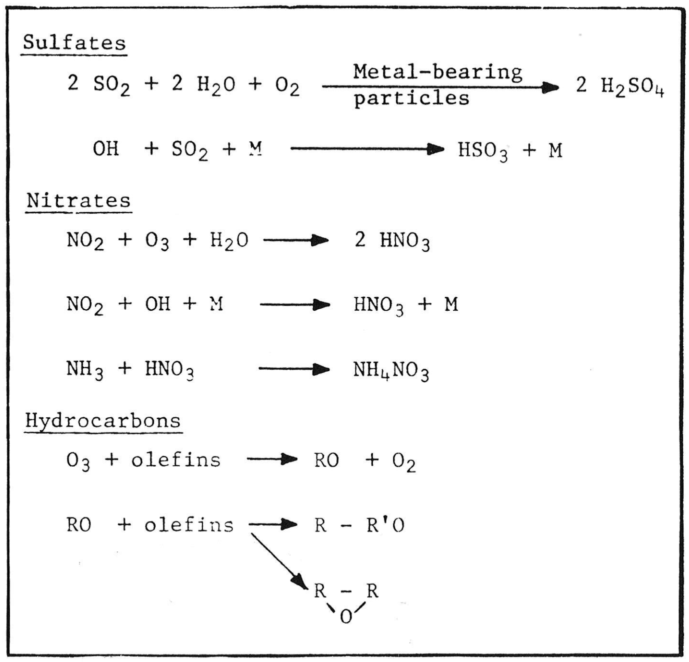

Fig. 4. Examples of some formation mechanisms involved in secondary airborne particulate formation.

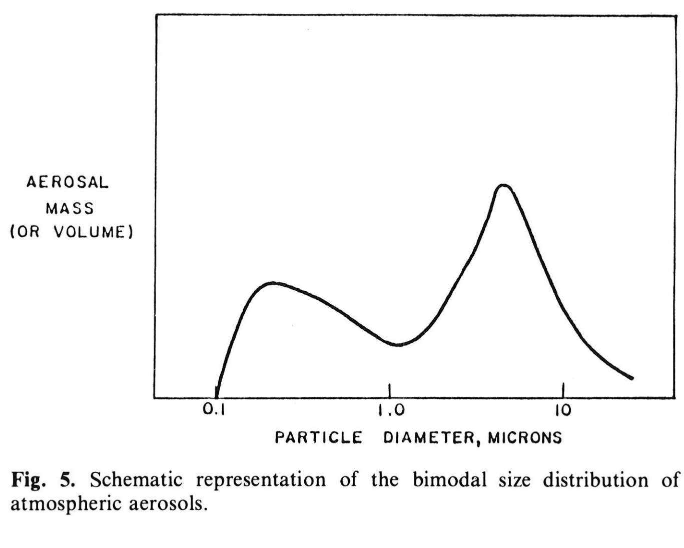

Fig. 5. Schematic representation of the bimodal size distribution of atmospheric aerosols.

particulates, etc.). The correlations were so impressive that the authors point out that the only way to discredit the results would be to postulate that the "real" cause of ill health was a third unknown agent which happens to correlate with levels of air pollution–an event that seems most unlikely. Their cost estimates are summarized schematically in Fig. 6. These estimates are conservative and, of course, do not account for the inflation which has occurred since 1970. Perhaps a more relevant index of the cost of air pollution would be their estimate that a decrease of about 4.5% of all economic costs associated with morbidity and mortality could be achieved by a 50% reduction of air pollution in our major urban centers.

SUMMARY

Particulates play a crucial role in influencing both local and global atmospheric behavior. Current standards are 75 $\mu g/m^3$ on an annual average basis and 260 $\mu g/m^3$ for any given 24-hr period.

Generally particulates are classified as primary or secondary. Primary particulates are those injected directly into the atmosphere from natural or anthropogenic sources. Secondary particulates which are usually composed of sulfates, nitrates, or hydrocarbons are the end products of chemical reactions occurring in the atmosphere. Secondary particulates are gaining increased attention with respect to control strategies. Currently under consideration in some quarters are separate concentration standards for fine particles (ie, all particles $< 3\ \mu m$ diameter) as well as sulfates, and nitrates. Also being considered are separate standards for atmospheric visibility in remote areas, which can be linked to fine particulate concentrations.

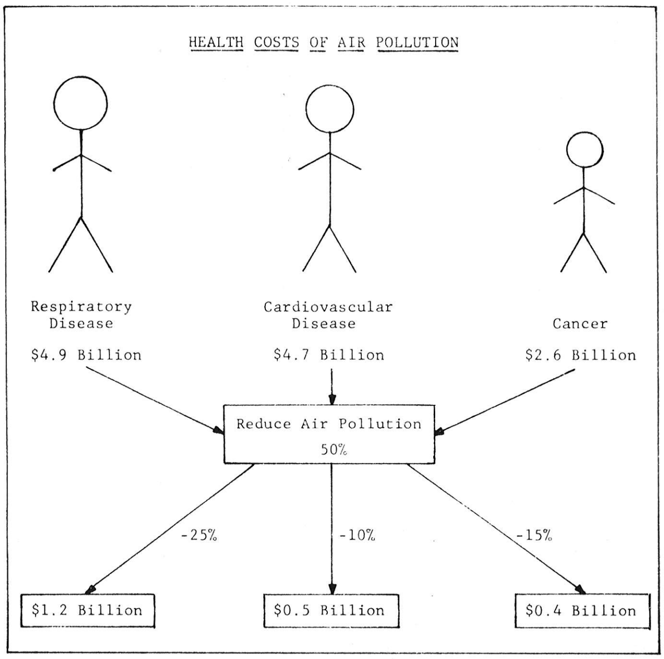

Fig. 6. Schematic representation of the costs of the health effects of air pollution. (Reprinted from Health Phys. 12:173 [4]).

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