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Air Pollution in the Urban Environment

Economic and Technical Review
Report EPS 3-AP-73-6

Air Pollution Control Directorate
August 1973

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by

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Air Pollution Control Directorate
Environmental Protection Service

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Information Canada
Ottawa, 1974

TRI-GRAPHIC PRINTING LTD. — CONTRACT NO. KE204-4-PO44A

ABSTRACT

A general discussion of urban air pollution and its control is presented in this report. The basic issues are defined, and the extent and sources of pollution are indicated. The effects of air pollution on the population are summarized with particular attention given to the health problems posed by the various pollutants. Finally, the technologic and economic philosophies of abatement and control are offered with a challenge issued to future generations to explore the many still unanswered questions surrounding this topic.

RÉSUMÉ

Le présent rapport renferme une discussion générale sur la pollution atmosphérique dans les villes et sur la lutte contre cette pollution. On définit les questions fondamentales et l'on donne l'étendue et les sources de la pollution. On résume les effets de la pollution atmosphérique sur la population en portant une attention particulière aux problèmes d'hygiène posés par les divers polluants. Enfin, on présente les principes technologiques et économiques de la lutte contre la pollution en lançant un défi aux générations à venir qui devront explorer les nombreuses questions qui se posent dans ce domaine et qui restent sans réponse.

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1 INTRODUCTION

Air pollution is today one of the most difficult and sensitive problems with which both government and industry must deal. It is difficult because of its complexity and sensitive because of an increasingly deep and often emotional public concern. This concern has increased almost explosively in the past 2 years, although it had been developing gradually over the past 20 years. One can hardly pick up a newspaper or a magazine today without reading about the subject.

Air pollution is, however, hardly a new problem. References to it date back to the 14th century and coincide with the introduction of coal as a source of heat. The problem became intensified again during the industrial revolution. Today air pollution has reached new heights as a direct result of our increasing urbanization, industrialization, and use of the automobile. The world-wide trend is for more and more of the same.

In recent years, a number of dramatic air pollution episodes, under very adverse meteorological conditions, have made us increasingly aware of the possible dangers of air pollution. As a result we now realize that we can no longer assume that the atmosphere has an unlimited capacity to handle and render harmless discharges under all circumstances. This realization has led to additional control legislation in many countries. The spectre of the possibility of global pollution has now been introduced.

In addition to this new awareness of environmental problems, public pressure for action has been influenced by changing social values resulting from our increased affluence. To some people the pollution problem has now become a simple matter of determining priorities for action. The difficulty arises, however, when these priorities have a different impact and a different significance when viewed from the position of the business executive, the scientist, or the general public.

2 THE NATURE OF THE PROBLEM

In describing the nature of the problem it becomes important at the onset to ensure an understanding of what is meant by the term 'air pollution'. The following definition has been suggested for legal purposes: 'air pollution' means the presence in the outdoor atmosphere of one or more air contaminants in such quantities and duration and under such conditions that may cause discomfort to or endanger the health, safety, and welfare of persons, or that may cause injury or damage to plant or animal life or property, or that interferes unreasonably with the normal enjoyment of life or use of property or conduct of business.

An 'air contaminant' means a solid, liquid, gas, odor, or combination of any of them that may contribute to or create a condition of air pollution. An air contaminant, therefore, need not be an air pollutant and this distinction can sometimes become important. In a 1970 study conducted by the Department of the Environment the five most common air pollutants in Canada were carbon monoxide (55.4%), sulfur oxides (23.1%), hydrocarbons (9.8%), particulates (7.3%), and nitrogen oxides (4.4%). It should be noted that these rankings are in order of weight emitted and do not parallel the order of effects produced by any means.

The atmosphere is a dynamic system. It steadily absorbs a range of pollutants, solids, liquids, and gases arising from both natural and man-made sources. These substances may accumulate or they may travel through the air, disperse, or react among themselves and with other substances both chemically and physically. Meteorology and air pollution are, therefore, intimately related in many ways. Once air currents are set in motion, pollution can be dispersed. How well and how fast depends on still other atmospheric factors such as stability, thermal and mechanical turbulence, mixing depths, inversions, wind direction, and wind speed. These factors are themselves affected by the time of day, the season of the year, the topography of the land, and the prevailing weather. It becomes possible, therefore, to predict the air pollution potential of a geographical area. A high air pollution potential would be indicated by a set of weather conditions conducive to the accumulation of air pollutants in the atmosphere. The major air pollution disasters (London, Donora, and the Meuse Valley) have all occurred during prolonged periods of light winds (poor horizontal ventilation) and temperature inversions (poor vertical ventilation). The Canadian Arctic is an example of an area which experiences long periods of high air pollution potential during the winter months. Fortunately there are few emissions occurring in that area.

Weather can also affect air pollution in other ways. Sunshine is required in the photochemical production of oxidants forming smog. Rainfall has a scavenging effect in washing out particulates. Finally, the humidity or the presence of fog can be a frequent and important factor in determining the effect of pollutants on property, vegetation, and health.

Atmospheric chemistry plays an important role in defining the nature of any air pollution problem. New and different pollutants are known to be created by the chemical interaction of air contaminants with each other. These mechanisms include photochemical and free radical reactions, oxidation and reduction, catalysis, and many others. Sulfur dioxide undergoes oxidation to sulfur trioxide, which combines readily with water vapor to form sulfuric acid as a mist or liquid aerosol of small particle size. The chemical reaction between nitrogen dioxide and certain hydrocarbons during irradiation by sunlight leads to the formation of increased levels of ozone and oxidants, a condition referred to as photochemical smog.

3 SOURCES OF AIR POLLUTION

By far the greatest source of air pollutants results from the combustion of fossil fuels. Other important sources are present in certain industrial activities such as iron and steel manufacturing, metal smelting, oil refining, pulp and paper, and chemical and petrochemical operations. An inventory of Canadian emissions for 1970 compiled by the Department of the Environment divided pollution sources into five categories with the following results: transportation, 56.9%; industrial processes, 24.5%; fuel combustion in stationary sources, 8.3%; solid waste disposal, 2.7%; and miscellaneous, 7.6%. Again this ranking bears no relationship to the contribution that each of the major categories makes toward the quality of the ambient air. For example, if we use as a weighting factor their respective concentration limits at which adverse effects begin to occur we find that sulfur dioxide, on an equal mass basis, would appear to be a more severe air pollutant than is carbon monoxide. Therefore on an air quality basis, power plants emitting SO_2 in an urban environment can often constitute a more serious air pollution problem than does the automobile.

Emissions of pollutants may be solid, liquid, or gaseous. Solid and liquid particulate matter may be either dustfall or suspended aerosols depending on the size of the particles. The dustfall distribution in cities is a useful indication of the amounts of fly ash and dust emanating from stack emissions. Most of these particles are in the 20 to 40 μm range and settle out fairly rapidly by gravity. They originate mainly from the combustion of solid fuels or industrial processes involving coarse dust emissions. Values of 50 to 100 tons per square mile per month are found in heavily polluted cities burning large quantities of coal. There is a distinct seasonal variation due to the increased fuel consumption in the winter months.

Suspended particulate matter includes both solid and liquid particles ranging from 100 μm down to 0.01 μm or less. Concentrations may vary considerably and can arise from several different sources. Typical values for suspended particulates in urban areas range from 50 to 200 $\mu g/m^3$ of air.

Sulfur dioxide is a major contaminant in urban and industrial areas where large quantities of solid and liquid fossil fuels are utilized for the generation of electric power, steam, and heat. It is also a major waste product in the smelting of sulfide ores, refining of petroleum, and manufacture of pulp and paper. In most urban areas the average concentration of sulfur dioxide exhibits a distinct seasonal variation increasing during the colder months of the heating season. Seasonal variations usually show a peak in December or January of an average monthly concentration of about 0.2 ppm (530 $\mu g/m^3$).

Carbon monoxide, the most abundant by far of any air pollutant, originates primarily from the exhaust of motor vehicles with smaller amounts coming from other forms of combustion. Concentrations over city streets vary with the density of city traffic. The highest concentrations are recorded in the commercial and industrial districts of large cities. These range from 20 to 40 ppm (23 to 47 mg/m^3) with maximum values peaking at 70 ppm (82 mg/m^3) for short periods.

Nitrogen oxides arise principally from combustion processes with the most important single source being the internal combustion engine. The automobile is an important source of hydrocarbons, other sources being solvent evaporation from surface coating operations and losses from petroleum refining. Neither nitrogen oxides nor hydrocarbons, however, reach concentration levels by themselves high enough to be of concern. Their significance in the atmosphere results when they react together under the influence of sunlight to form 'secondary pollutants' that can cause concern. Oxidant levels expressed as ozone, one of these secondary pollutants, have been used to measure the overall severity of 'photochemical smog'. Concentrations in excess of 0.5 ppm (1000 $\mu g/m^3$) have been noted in Los Angeles. This type of air pollution has not yet appeared as a problem in Canada although some oxidant levels greater than 0.1 ppm (200 $\mu g/m^3$) have been recorded in Toronto.

4 EFFECTS OF AIR POLLUTION

The greatest need for a better understanding of air pollution lies in a most crucial area. That area is the one which deals with its mode of action and consequent effects on man, animals, plants, and inanimate materials as well as on the total ecological system. Air pollution today affects to some degree virtually the entire urban population. Some people seek an end to air pollution because it soils the paint on their homes or interferes with the growth of ornamental plants. Others are interested in the abatement of air pollution because they are tired of brushing soot off their window sill. Still others are concerned because it interferes with their professions as, for example, airline pilots, city planners, farmers, and manufacturers. Many just don't like the smells that assail them where they live or work and many are simply annoyed when the mountains, forests, or other aesthetic delights they enjoy become obscured by blankets of smog. All these people have good reasons for wanting to see air pollution controlled. All would agree, however, that the primary reason for the control of air pollution in the urban environment must be that it threatens human health.

Human health does not have a satisfactory medical definition. In abatement action brought under the U.S. Clean Air Act, the definition of the World Health Organization has been applied. This definition says that health is a state of complete physical, mental, and social well-being rather than merely the absence of disease or infirmity.

Following this definition we find that there are two main categories of air pollution effects on human health. The first type causes discomfort and annoyance. Eye and nasal irritation, odors, and similar complaints may or may not result in any permanent physical impairment. These effects are, however, felt by the bulk of the population and therefore, in the short term, are most likely to determine public reaction.

The second category of health effects involves actual physical injury. The recognized cases of injury resulting from air pollution usually involve a small part of the population that is often already in a marginal state of health. The most dramatic illustrations of this kind of adverse health effects are the air pollution disasters that have overtaken both large and small communities. During such episodes serious illness was sudden in onset and in some cases fatal. The best known of these occurred in London in December, 1952, when a 4 day period of still air caused pollution to accumulate in a pea soup fog. Months later a review of mortality statistics revealed that 4000 excess deaths had occurred and that the cardiorespiratory illness rate had increased to more than twice the normal rate for that period.

Air pollution episodes are of course alarming, but of greater concern today is the long-term effect of much lower levels of air contaminants on those who live in a continuously polluted atmosphere. Air pollution is no doubt a contributing factor to the rising incidence of chronic respiratory diseases including lung cancer, emphysema, bronchitis, and asthma. In general, these chronic diseases develop slowly over long periods of time. As a consequence, it becomes difficult, if not impossible, to satisfy traditional scientific criteria for establishing a direct cause and effect relationship between exposure to air pollution and the development of chronic respiratory disease. This problem has been the subject of much research over the last 15 years. A substantial body of factual information has been collected. Despite all the uncertainties and variables the main thrust of the evidence to date indicates that air pollution is contributing to chronic respiratory disease.

Several methods are available to the medical scientists in their quest for knowledge on the health effects of air pollution. These include the retrospective examination of industrial accidents and acute air pollution episodes, epidemiological and clinical studies, and controlled laboratory investigations. Direct evidence of danger to humans can sometimes be based on long-range animal experimentation. Animal experiments, however, do not adequately simulate the prolonged exposure of humans since the development of diseases in humans can extend over many years. In addition, there is the problem of species differentiation. Clinical studies that concern themselves with the actual disease in the living subject are especially valuable today since the development of precise techniques for measuring pulmonary function. The largest amount of data on this subject has come from epidemiological surveys. These surveys of selected population groups are subjected to statistical analysis to assess the independent effects of air pollutants. The results have for the most part indicated a strong relationship between the severity of health effects and the degree of air pollution as indicated by the levels of such pollutants as particulate matter and sulfur dioxide.

Studies are also being conducted in an effort to determine how air pollutants produce their adverse health effects. Their major effect on health, to date, appears to be the result of irritant materials acting on the respiratory tract. Certain irritants, either gaseous or particulate, can slow down and even stop the action of the cilia, the hair-like cells that line the airways, thus leaving the sensitive underlying cells without protection. Irritants can cause increased production or thickening of mucus. They can cause constriction of the airway passages. They can induce inflammation with excessive growth of cells or destruction of normal lung tissue. As a result of any one or more of these modes of action, breathing may become more difficult and foreign matter including bacteria may not be effectively removed so that respiratory infection can more easily result.

When we examine the effects of individual air pollutants there is considerable evidence that the oxides of the sulfur family, the second greatest in total quantity, is one of the most important. This includes sulfur dioxide, sulfur trioxide, and their corresponding acids and salts. Sulfur dioxide alone can irritate the upper respiratory tract but only at relatively high concentrations not usually encountered in the ambient air. The gas is quite soluble and is rapidly dissolved in the nasal mucus before it can reach vulnerable tissue. When the gas is adsorbed on airborne particulates, however, it can be carried deep into the respiratory tract where it can injure delicate tissue unprotected by mucus. Moreover, in this way, significantly larger concentrations result than would if the gas itself were inhaled.

Another mechanism by which sulfur dioxide may exert its effect on man involves its oxidation to sulfur trioxide, which in the atmosphere immediately converts to sulfuric acid mist. This reaction may occur either photochemically or by catalysis on the surface of certain airborne particles. Under conditions of relatively high humidity, in excess of 70%, especially in the presence of fog, a considerable proportion of the sulfur dioxide may form sulfuric acid; investigators have reported conversions to acid ranging as high as 50%. The acid is, of course, far more detrimental to lung tissue when inhaled than sulfur dioxide. Either of these two mechanisms can account for the synergism between particulate matter and sulfur dioxide. Both probably operate at the same time to varying degrees as determined by other external factors.

Adverse health effects associated with sulfur dioxide have been indicated in individuals with chronic respiratory disease when 24 h average levels exceed 0.11 ppm (290 $\mu g/m^3$) for 3 to 4 days and when the annual mean level exceeds 0.04 ppm (110 $\mu g/m^3$). Interestingly the 5 day average during the 1952 episode in London was 0.57 ppm (1500 $\mu g/m^3$) with a peak at 1.3 ppm (3500 $\mu g/m^3$). This was, of course, accompanied by a high particulate loading including dense fog.

Particulates can also exert a deleterious effect in their own right. The size of airborne particles has an important bearing on whether and to what extent they exert a pathological effect. Coarse material - about 5 μm or more - will lodge in the nasal passages. Smaller particles are more likely to penetrate into the lungs, the rate of penetration increasing with decreasing particle size. Particles smaller than 2 - 3 μm usually reach the deeper structures of the lungs not protected by a mucus blanket. It has been estimated that about one-half by weight of all suspended particulates are respirable.

The ability of particles to accentuate the adverse physiological effects of simultaneously inhaled gases is one of their most important aspects. Particles, however, may be quite complex in their chemical composition. Materials found in airborne particles include aliphatic and aromatic hydrocarbons, acids, bases, phenols, and a wide range of metallic elements. Any one of these substances, when present in airborne particulate matter, may independently exert its own pathological or other physiological effect when inhaled.

Adverse health affects associated with particulates have been noted when annual mean levels exceed 80 $\mu g/m^3$. On the other hand, levels as high as 700 $\mu g/m^3$ have been observed for short periods without harmful effects. Clearly in many instances the presence of other pollutants determines the permissible levels of particulates insofar as health effects are concerned.

Of considerable interest recently is the role played by carbon monoxide, our most abundant air pollutant. Although atmospheric concentrations of carbon monoxide have no primary direct effect on body tissue, they do have an indirect effect on the central nervous system and may also aggravate heart disease. Concern also arises from the uncertainty about possible long-term effects of continued exposure at concentrations below the clinically toxic level. There does appear to be some adaptation to carbon monoxide which may be related to cigarette smoking - a potent source of carbon monoxide.

Carbon monoxide produces its primary biological effect in the blood stream through the inactivation of hemoglobin. By having 210 times the affinity for hemoglobin that oxygen does, it displaces the oxygen to form carboxyhemoglobin. This lack of oxygen in the blood and circulating system, a condition known as anoxia, affects other body organs. The symptoms are headache, irritability, dizziness, and general fatigue. Oxygen deficiency in the myocardial region, the middle layer of the heart wall, would support the clinical foundation for speculation that carbon monoxide can aggravate heart disease. Animal experiments have also substantiated this view.

Exposures of eight or more hours to a carbon monoxide concentration of 15 ppm (17 mg/m^3) have produced impaired time interval discrimination in nonsmokers. Levels of 30 ppm (35 mg/m^3) have elicited impaired performance by nonsmokers in certain psychomotor tests whereas higher levels have produced evidence of physiological stress in studies on patients with heart disease.

In any review of urban air pollution mention should also be made of other effects besides those of health which at times can be quite important. Some of these become particularly significant when economics are considered. The most obvious effect of air pollution is the limit it puts on visibility. A reduction in visibility to about 5 miles is observed with levels of sulfur dioxide at 0.10 ppm (270 $\mu g/m^3$) or with levels of particulate matter at 150 $\mu g/m^3$. Nitrogen dioxide, which peaks during morning rush hour traffic, absorbs light in the blue region of the visible spectrum and is responsible for the brown haze over many urban centres. Air pollutants can also abrade, corrode, tarnish, weaken, and discolor materials of all kinds. Adverse effects on materials have been observed with levels of sulfur dioxide as low as 0.12 ppm (320 $\mu g/m^3$). These levels when accompanied by particulates increased the corrosion rate for steel panels by 50%. Adverse effects on materials by particulates are observed when annual mean levels exceed 60 $\mu g/m^3$.

One of the most widespread effects of polluted air is damage and destruction to vegetation. Indeed, many plants are more sensitive to some air pollutants than are humans and animals and, therefore, can be used as indicators for the presence of these air pollutants. In the case of sulfur dioxide, for example, adverse effects on vegetation have been observed at average levels as low as 0.03 ppm (80 $\mu g/m^3$).

5 PRESENT CONTROL METHODS

The practice of air pollution control is, however, often limited by the costs involved. The distinction between costs and technical feasibility is an important one and is often obscured in public debate. Technology is available for controlling most pollutant emissions to the degree that may be required. The development and application of this technology has, however, sometimes lagged - perhaps because of the absence of legal compulsion or perhaps because there has been little economic incentive to develop better control methods. Notwithstanding this, some important and obvious omissions are apparent in the technology that is available. One of these is the absence of commercially proven methods for the control of sulfur oxides from combustion processes used for generating electricity. For some air pollution problems it may eventually evolve that there are no inexpensive solutions. In such cases, the requirement for control may prove to be a revision of our ideas as to what constitutes a reasonable cost.

Many of the tools we use to control air pollution today are well known. These include such things as electrostatic precipitators, settling chambers, cyclones, filters, and scrubbers, which remove pollutants from the process effluent. We can also remove the pollutant or its precursor from the process inputs. Conversion to cleaner burning fuels and the desulfurization of fuels fall into this category. Operating the process so as to minimize pollution or replacing a process completely by one that doesn't cause air pollution are considered more drastic measures. All these methods are in use today and have resulted in significant progress in the abatement of air pollution in a number of problem areas.

The City of London is a good example of what can be done. There the conversion to smokeless fuel and government subsidies for modifying furnaces and grates have performed a visible miracle. Londoners have bought themselves 50% more winter sunshine and visibility has tripled to 4 miles. The old pea soup fogs are gone and varieties of birds which haven't been seen for years are now reappearing in the centre of the city.

6 ECONOMIC CONSIDERATIONS

In any analysis of the air pollution problem a consideration of economic factors is an essential part. This field is now drawing a substantial amount of attention from the economists. A complete benefit - cost analysis would be an enormous undertaking. In any calculations made to date, the marginal benefits of increased control measures have always far exceeded the marginal costs required. The benefits to be derived from a cleaner atmosphere are far reaching and include among them many intangibles. Fortunately, they also include a number of tangible benefits which can be quantified. Some of these benefits arise from a reduction in economic losses resulting from increased health costs, property damage, maintenance and cleaning costs, and personal grooming costs.

Although relatively little research has been devoted to date on the determination of costs and economic losses due to air pollution, nevertheless a few studies are worthy of mention. One of these was the year-long investigation conducted by Michelson and Tourin and published in U.S. Public Health Reports, June, 1966. These workers compared Steubenville, Ohio, and Uniontown, Pennsylvania, with respect to home maintenance costs both inside and outside, laundry and dry cleaning costs, and hair and facial care costs. The criterion for selecting these two communities was their similarity in every way except in the level of air pollution where the difference was to be as great as possible. At the time of this study the annual average particulate levels were 383 $\mu g/m^3$ for Steubenville and 115 $\mu g/m^3$ for Uniontown. After analyzing all their data the authors concluded that the increased home and personal care cost resulting from the higher pollution levels in Steubenville was $3 100 000 annually or $84 per capita. This figure would, of course, be higher today.

In another more recent study the increased health costs resulting from air pollution in the United States were examined by Lave and Seskin of the Carnegie-Mellon School of Industrial Administration. Their report published in the August 21, 1970, issue of Science concluded that if current air pollution levels were to be reduced by 50%, the savings in health costs would reach $2 billion in the United States.

Extrapolating the results from such studies enables one to estimate what these same economic losses are in Canada. On doing this, we arrive at a figure in the neighborhood of $1.5 billion annually or approximately $75 per capita.

On the other side of the benefit - cost formula, economic considerations can lead to some very real conflicts of interest in relation to industrial production. Occasionally, the substantial expenditures required for air pollution control measures will drastically affect the competitive position of whole industries, in the domestic as well as the international marketplace. This economic problem goes beyond the immediate one of nonproductive overheads. It involves all levels of government in difficult choices in establishing air quality objectives and standards that reflect not only scientific criteria but socioeconomic considerations as well.

7 THE FUTURE

In looking to the future many hopeful signs permit predictions of an improved situation. Emissions of sulfur oxides will be gradually controlled over the next 20 years through desulfurization as well as through removal of SO_2 from stack gases. The requirements for electrical energy, however, are expected to more than double during the same period and as a result our best efforts will probably do no more than to hold the line on total emissions from this source. Process changes rather than the addition of control equipment will become a principal pathway to emission control. The requirement for such control will often be a major factor in determining plant modernization or replacement. Finally, the successful development of the breeder nuclear reactor and its wide application after the year 2000 will result in a rapid decrease in sulfur oxide emissions. The rising cost of fossil fuels would further add to the economic advantages of nuclear power generation.

The problem of air pollution will be with us for some time to come. Scientists are now searching for long-term subtle effects on the human life span. They are likely to find some. They are also beginning to look for possible effects on climate and global ecology. It is not unlikely that some of these will also be confirmed. In addition, as a result of increased urbanization and population growth, the future will surely bring even greater demands on our ability to control the pollution of our atmosphere. These demands can only be met through the application of science and a greatly increased research and development effort by governments, universities, and industry.