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AIR POLLUTION

Fifth Report of the Expert Committee on Environmental Sanitation

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EXPERT COMMITTEE ON ENVIRONMENTAL SANITATION

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Members :

Dr E. C. Halliday, Head, General Physics Division, National Physical Research Laboratory, Council for Scientific and Industrial Research, Pretoria, Union of South Africa

Dr Harry Heimann, Chief, Operational Research Section, Air Pollution Medical Program, US Public Health Service, Washington, D.C., USA

Dr E. Leclerc, Directeur du Centre belge d'Etude et de Documentation des Eaux, Université de Liège, Liège, Belgium

Dr Louis C. McCabe, President, Resources Research Inc., Washington, D.C., USA (*Rapporteur*)

Dr Albert Parker, formerly Director of Fuel Research, Department of Scientific and Industrial Research, London, England (*Chairman*)

Dr C. A. Ragazzi, Director, Municipal Office of Hygiene, Milan, Italy

Dr M. N. Rao, Professor of Physiological and Industrial Hygiene, All-India Institute of Hygiene and Public Health, Calcutta, India

Representative of the World Meteorological Organization :

Dr M. A. Alaka, Technical Officer, Investigations Section, WMO, Geneva

Secretariat :

Mr H. G. Baity, Director, Division of Environmental Sanitation, WHO

Mr R. N. Clark, Chief Sanitary Engineering Adviser, Division of Environmental Sanitation, WHO (*Secretary*)

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EXPERT COMMITTEE ON ENVIRONMENTAL SANITATION

Fifth Report *

AIR POLLUTION

1. INTRODUCTION

In the atmosphere, just as in natural surface waters, pollution of various forms is continually being introduced and continually being removed by the self-cleansing actions of the medium; but when the rate of pollution becomes too high, or when the cleansing process itself becomes ineffective, then excessive and dangerous concentrations result and a health hazard exists.

In the past century industry has rapidly expanded, congested population centres have grown up and motor transport has come into common use, all of which have resulted in an increase of air pollutants. This has led, on occasion, to the accumulation in some places of air pollutants to levels of concentration that have caused serious illness and death. The World Health Organization, recognizing its responsibility in the matter of air pollution as a threat to the health and well-being of peoples throughout the world, has taken its first steps to marshal the facts and to suggest procedures by which preventive and remedial action may be taken by its member countries before serious harm is done to the health of their people.

In a strict sense, pollution of the atmosphere can be said to exist whenever any substance, aside from the inert air gases and moisture, is present in that atmosphere which does not serve a useful function. Unpolluted air in this sense, however, is rarely found on earth. It is reasonable, therefore, to consider that the term air pollution be limited to the situations in which the outdoor ambient atmosphere contains materials in concentrations which are harmful to man or to his environment. The Committee,

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* The Executive Board, at its twenty-second session, adopted the following resolution:

The Executive Board

1. NOTES the fifth report of the Expert Committee on Environmental Sanitation (Air pollution);

2. THANKS the members of the Committee for their work; and

3. AUTHORIZES publication of the report.

(Resolution EB22.R27, *Off. Rec. Wld Hlth Org.* 1958, **88**, 11)

in considering this definition and its own responsibility, has decided to limit itself to man-made air pollution only and to exclude from consideration the pollutants of natural origins, such as pollen, products of volcanic activity or of the decay of rocks and organic matter, and dusts from outside the earth's atmosphere.

2. RECOGNITION AND EVALUATION OF POTENTIAL OR ACTUAL CONDITIONS OF AIR POLLUTION

2.1 Recognition

Usually the first awareness of air pollution is through limited visibility, damage to vegetation, deterioration of materials, or effects on man. In the latter instance there may be strong or unusual odours, irritation of membrane surfaces, grit underfoot or an acid taste in the mouth. These are subjective phenomena but are no less useful in the identification of the air-pollution problem because they vary with the individual. While sensory perception may provide the first indication of the presence of most contaminants in the atmosphere, it is often not possible to detect trace quantities of many airborne toxic substances or the presence of radioactive matter through the senses. Their identification requires physical measurement.

Identification and measurement of air pollution are important to understanding and control. Exclusive of pollen, fog and dust of natural origin, about 100 contaminants have been identified. Smoke is perhaps the most easily recognized air contaminant. The oldest and best-known effort to apply an objective measurement to it was made by Maximilien Ringelmann about the turn of the century.

Air contaminants are produced by nature and the activities of man; they occur as gases, liquids or solids and are in a state to be transported by movement of the air. Contaminants arising from human activities (the principal concern of this report) occur in the air in the solid, liquid or gaseous state as a variety of substances which include sulfur, nitrogen, carbon, oxygen, halogen and other compounds. Industrial or domestic sources may produce them for short or protracted periods.

Radioactive contaminants of the air are gaining importance. They also may be encountered in the solid, liquid or gaseous state. Background amounts of radon and thoron and daughter products, resulting from naturally-occurring uranium and thorium rocks of the earth's surface, are present in the atmosphere. Recent scientific advances have added more radioactive elements to the atmosphere : for example, effluents from nuclear reactors, nuclear chemical processing plants, radiochemical laboratories and hospital incinerators, and " fall-out " from nuclear weapon tests.

2.1.1 *Nature of pollutants*

Solids and liquids may be sub-divided in relation to their origin. Dusts are solid particles formed by some disintegration process such as crushing, grinding or demolition. Normally their size is larger than 2μ but may be as small as 0.1μ. Fumes are solids generated by the condensation of vapours, and may result from sublimation, distillation or from chemical reactions. The normal particle size is less than 1μ. Fumes are often metals or their oxides, and their composition may differ materially from the substances from which they originated. Liquid droplets smaller than 10μ in diameter are generated by condensation. Sprays are larger liquid droplets which are created by some mechanical disintegration process. Unlike many of these solid and liquid contaminants, most of the gaseous pollutants in the air are invisible.

The world's use of fuel is rising rapidly at the present time because of expanding industrialization ; as a result, atmospheric pollution is increasing too. The main natural sources of the energy required for industrial production are coal and oil. Either of these fuels may produce smoke if burned in improper equipment, or if the equipment is improperly operated. When oil is used in place of coal as a source of heat and power, pollution by smoke and dust is reduced, but there is usually no reduction in the output of sulfur dioxide.

With increasing industrialization as well as with the mechanization of transportation and agriculture, the demands for energy are on the verge of outstripping the capacity to supply them conveniently and economically from conventional sources. It is for this reason that so much interest is now attached to the development and use of nuclear sources. The use of nuclear energy produces a new and potentially more hazardous source of air pollution.

The naturally-present radioactive contaminants in the air—radon, thoron and daughter products—are of minor importance. Effluents such as argon 4, from air-cooled reactors, may be only of very temporary significance but a variety of others such as carbon 14 from CO_2-cooled reactors, or iodine 131 and krypton 85 from chemical processing plants, or mixed effluents from radiochemical laboratories, may be of greater significance.

The oxides of sulfur have been studied longer and more intensively than any other pollutants, and their effects on plants and materials are fairly well understood. The toxicological reactions in human beings caused by inhalation of these oxides are not too well defined as disease syndromes. The symptoms described by the affected individual, however, indicate that the sulfurous gases significantly contribute to the irritation of the membranous surfaces.

Only recently has pollution of the atmosphere by organic compounds from incomplete combustion products of industry, automobile traffic, incineration of wastes and evaporation of gasoline been recognized as of major significance. The organic compounds, particularly the intermediate olefines, are oxidized by photochemical reactions and form a wide spectrum of compounds, many short-lived, including ozonides, peroxyacids, peroxynitrites or -nitrates, adehydes and acids, together with polymerization compounds which form aerosols and reduce visibility. The leafy vegetables, such as spinach, romaine, endive (chicory), and also table beets, Swiss-chard and celery, are injured by " smog " of organic origin. Characteristic lesions are produced which are initially apparent as a bronzing or silvering of the lower epidermis of the leaf. Present medical knowledge on the pharmacological and toxicological action in man of many of these substances is meagre, though it is known that the action of certain combinations of these products varies from simple lachrymation to an oedematous condition of the lungs.

Hydrogen fluoride and silicon tetrafluoride are toxic to some plants in concentrations as low as 0.1 part per 1000 million (p.p.b.). All fluorides, gaseous or particulate, may accumulate in forage to build up concentrations greater than 50 parts per million (p.p.m.) on the inside and outside of the leaves. Ingestion of forage bearing excessive amounts of fluoride has caused fluorosis in cattle on pasture-lands exposed to airborne fluorides from aluminium reduction, smelting of iron and non-ferrous ores, ceramics manufacture, phosphate reduction and phosphate fertilizer production. Fluoride poisoning in humans from airborne sources is not well documented. Potential hazard through water and soil contamination has, however, been recognized. Contamination of water may originate from deposition of fluorides from the atmosphere over the watershed.

2.1.2 *Meteorological and physiographical factors*

The atmosphere is the medium in which air pollution is transported away from the source to the receptor. It is also a diffusing agent which disperses the contaminating material. Therefore, for a given source strength, the state of the atmosphere governs the frequency, duration and concentration of air pollution to which a given receptor will be exposed.

2.1.2.1 *Wind flow*

The basic parameter governing the transport of contaminants by the atmosphere is the wind speed and direction. Generally speaking, wind flow increases in winter, especially in temperate and polar latitudes. Occasionally, however, and particularly in the interior of large continents, prolonged periods occur during which there is little or no air motion. Light variable winds not only result in decreased rate of transport of contaminants

but may also cause the return flow of material across the original source. In the USA, late spring and early fall are most favourable for such situations, whereas in Europe they occur most frequently in late fall and early winter. In addition to the seasonal change in wind speed, there is a diurnal change which may be even more marked. During the night the low-level wind is generally weaker than during the day-time hours so that transport of low-level pollution is in general more effective during the day than at night.

2.1.2.2 *Turbulence*

The mechanism by which dilution of the contaminant is most effectively achieved by the atmosphere is turbulence or eddy motion. Turbulence is essentially composed of two components, mechanical and thermal. The former varies with the strength of the wind and the roughness of the surface ; the latter is a function of the stability of the atmosphere.

The rate of decrease in the value of any meteorological element with elevation is usually referred to as its lapse rate. With a normal or standard atmosphere, the temperature lapse-rate is 3.5°F/1000 ft (0.64°C/100 m). An air stratum with an inverted (positive) temperature gradient is known as an inversion. Of particular interest is the lapse rate which allows a parcel of air to be displaced from one level to another so that the parcel always has the same density as its environment. Such a lapse rate is known as the adiabatic rate and is equal to a decrease with elevation of 5.4°F/1000 ft (1°C/100 m) (assuming unsaturated air). When the vertical temperature gradient of the lower atmosphere is greater than the adiabatic lapse-rate, it is unstable. Vertical motions are then enhanced and dispersion takes place at a rapid rate. If, on the other hand, the lower atmosphere is stable, vertical motion is suppressed and the dilution of the pollutant is hampered.

2.1.2.3 *Inversions*

If there is an inversion of temperature, the atmosphere is characterized by extreme stability. Pollution released in such an atmosphere tends to be confined to a shallow layer. This effect is often enhanced by the fact that low-level inversions are generally accompanied by little or no wind so that both the lateral and the vertical dispersion of the pollution are impeded. During conditions of extreme stagnation, the pollution may reach such high concentration that the solar radiation reaching the ground is materially reduced, thereby permitting the inversion to persist for longer periods. Invariably, the most acute cases of pollution reported have occurred in atmospheric conditions characterized by temperature inversions near the ground and weak wind speeds. Low-level inversions most frequently occur as a result of nocturnal radiation of heat from the surface of the ground into space. On a cloudless day, near or shortly after sunset, the air near the

ground cools rapidly and an inversion gradually forms, increasing in intensity and depth during the night, and reaching a maximum between midnight and the time of minimum surface temperature. During this time contaminants released within or below the inversion layer are trapped in the layer. On the other hand, contaminants released from tall chimneys at levels above the inversion are not transported to the ground. With the coming of daylight, the ground begins to heat and the inversion is gradually destroyed from the ground upwards. The rapid mixing in the lower layers which ensues may result in bringing the pollution down to ground level. This is known as "fumigation".

Another type of inversion is that which prevails, for example, along the coast of California and which is caused by the cooling of the lower layers of the air by passage over the cold sea. Pollution problems in the Los Angeles area are greatly aggravated by the persistent nature of this inversion.

2.1.2.4 *Precipitation*

Dispersal of contaminants in the atmosphere does not remove the material but merely dilutes it. If most of the contaminants were not eventually removed by other processes, the lower layers of the atmosphere would gradually become intolerable to man. Perhaps the most efficient cleansing agent of the atmosphere is precipitation (rain and snow), which effectively removes both the particulate and gaseous contamination.

2.1.2.5 *Effect of topography*

In addition to meteorological factors, topography plays an important part in determining the concentration of contaminants in the atmosphere. With the exception of cases of severe pollution in London, all major air-pollution disasters hitherto studied have occurred in areas where the air flow was markedly restricted by terrain, so that the pollution was persistently and continuously channelled to, or confined in, a relatively small area. Within a narrow valley, the characteristic daily wind pattern is for flow up the slopes in the daytime owing to solar heating; after sunset the flow reverses and moves down the slopes into the valley. Contaminants released within the valley may be effectively trapped within a small area for long periods of time. Moreover, the valley is to a certain extent shielded from the effects of the general circulation pattern, with the result that lower wind speeds occur along the valley floor than would be the case with comparable level terrain.

2.2 Evaluation

Evaluation of air pollution embraces prevention and alleviation. To evaluate the actual pollution of the air, reliable air sampling procedures must be followed. Air samples, whether at the source or from the ambient

atmosphere, should be representative, and sampling errors minimized. Sampling is adequate only when continuous or frequently repeated, and best results are obtained when standard analytical techniques are used. The potential for air pollution must be studied in relation to the dispersive properties of the atmosphere, and this should include micro-meteorological studies (meteorology of the lower layers).

2.2.1 *Instrumentation and techniques*

In measuring the levels of atmospheric contaminants, many different methods commonly used in industrial air analysis are available, but with this difference—that the sensitivity of the methods must be higher in the case of atmospheric air samples. Concentration of pollution in the community ambient air is usually less, and more complex, than in work places. The Committee feels the need for international standardization of at least those techniques used most frequently for measuring such common contaminants as smoke, dust, and oxides of sulfur. The need for simplicity is emphasized.

Smoke is a universal air pollutant, and the degree of blackness may be measured by the Ringelmann chart or a similar device. Though the limitations of this method are recognized, it serves as a useful index for smoke control. Automatic smoke sampling and recording instruments are useful, especially when a standard device is in common use.

Dust is a universal contaminant. The methods used in its measurement depend on its physical characteristics and concentration. Such instruments as thermal and electrostatic precipitators, high-volume air samplers, cyclones, filters, or simple impingers may be used. It should be remembered that values obtained by different instruments are not strictly comparable, but repeated sampling with a standard instrument is of great value. The simplest sampling device used for evaluation of sedimentation of the airborne dust is the dust-fall jar.

Pollution of the atmosphere by chemical aerosols and gases may present complex evaluation problems. In assessing such atmospheric pollution problems, quantitative methods of chemical analysis or complex instrumentation may be required. The oxides of sulfur and nitrogen, aldehydes and ozone are examples of air contaminants that must be measured by standard gravimetric or volumetric methods or by automatic instruments specifically designed for the purpose.

The sampling of radioactive substances from the atmosphere is not materially different from the sampling of other contaminants. Rainfall may be collected in jars and its radioactivity measured, or high-volume samplers may be used to collect the airborne radioactive dust on a suitable filter and evaluated with a Geiger-Müller or similar counter. The Committee is of the opinion that, although these may be recommended for use in air pollution programmes, the techniques should be standardized and results interpreted by suitable technical agencies.

2.2.2 *Evaluation of potential or actual conditions of air pollution*

The predominant characteristic of the atmosphere is its continual change. Therefore its ability to disperse concentrations of pollutants varies tremendously. Some of the variations are governed by physical laws which are well known; others, especially those relating to parameters which are intimately connected with the dispersion of pollutants in the atmosphere, such as the turbulent structure of the wind, the low-level temperature, and wind gradients, are less well known. Nevertheless, it is possible to draw inferences from conventional meteorological data with regard to the frequency of meteorological conditions which would be conducive to high levels of air pollution. In addition, formulae have been developed which permit the concentration to be computed from single individual sources, and which give results in reasonable agreement with actual measurement. Proper utilization of these formulae would allow the conditions under which a given source can lead to excessive concentrations to be determined, and would also permit determination of possible recurrence of periods of high concentration.

2.3 Research

The more complex problems of air pollution have been recognized only recently, and knowledge is limited to scientific information gathered by a very few of the more advanced countries. These problems are global in nature and it would therefore be of great benefit if research were encouraged in Member States of the World Health Organization. To assist progress in the less developed countries, emphasis should be placed on measurement programmes which serve as baseline surveys.

Standardization of terminology is necessary. Allowing for the different systems of weights and measures, methods of reporting air contaminants should be standardized. There is a pressing need to standardize the simpler instruments and techniques which are already in use in some places—for example, methods of determining smoke, dust-fall, and sulfur oxides. It is recommended that WHO encourage such standardization.

3. EFFECTS OF AIR POLLUTION

The primary concern of the Committee is to consider the relationship that air pollution has to human health.[1] Although it recognizes that air pollution also causes damage to property, the Committee believes that consideration of such damage is within its purview only to the extent that

[1] According to the Constitution of the World Health Organization, " health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity ".

such property damage disturbs man's mental health. However, it is emphasized that reduction of air pollution accomplished for whatever primary reason will generally have a beneficial effect in other directions.

The effects of air pollutants may be conveniently divided into four categories, namely, (1) effects upon human health, (2) effects upon animals, (3) effects upon vegetation, and (4) economic and sociological effects.

3.1 Effects upon human health

Whereas it is generally accepted that community air pollution in unusual concentrations brought about by a combination of special weather conditions and topography has caused sickness and death, the Committee notes that human exposures to lower levels of air pollutants may also be harmful to health. Although not as fully documented as the severe acute episodes, air pollution of lower-air concentrations has been known on occasion to cause irritation of exposed membranous surfaces to such a degree that symptoms arising from such chemical irritation have caused discomfort to large numbers of people. Such disturbance of human comfort is recognized by the Committee as an adverse effect upon health. Furthermore, the Committee notes that membrane irritation is generally much more characteristic of the effect of air pollutants than are systemic reactions.

Whereas exposure to unusual accumulations of higher concentrations of irritant pollutants can cause adverse health effects, long-continued exposure to lower concentrations of the same or similar materials may not necessarily be harmful. In fact, adverse health effects from such exposure have not been proved epidemiologically, except in a few isolated studies. However, rational medical and epidemiological concepts lead to the belief that this matter must be studied on a large scale in many selected places before definite conclusions can be reached.

With regard to those air pollutants that are known and those that are suspected to be causes of harm to health, it is the opinion of the Committee that the current status of knowledge is not adequate to establish standards of what levels of concentration are safe for humans.

It is apparent from the foregoing that much more medical and epidemiological research is needed if control of air pollution is to be more soundly based on the need to safeguard human health. It is recommended that such research, carried on by competent personnel in many selected places in the world, should be directed in the following avenues:

(*a*) Field epidemiological investigations of those diseases currently suspected of being causally related to air pollution. Such diseases should include chronic bronchitis (in the broadest definition of that term) and primary lung cancer. To assist in such investigations, there should be agreement among nations on the definitions of the clinical conditions to be studied and for which the morbidity and mortality rates are to be compared by the epidemiologists.

(*b*) Suitably controlled laboratory investigations of substances that are suspect as air pollutants. Such investigations should include exposure of various species of animals, and must include the inhalational route of administration at levels of concentration that are known to be reached in the ambient community air. When gases are used in such toxicological investigations, experimental protocols should include exposure to the gases together with some inert aerosols. When toxicological investigations include exposure of human volunteers, due care must be exercised to avoid irreversible injury to the volunteers.

3.2 Effects on animals

The effects of air pollution on domestic animals are similar to those observed in man. This was shown to be the case in some of the severe air-pollution episodes that have been documented. Though the effects on animals in some circumstances are of economic importance, they are possibly of greater importance in indicating where to search for human effects.

The exposure of experimental animals to pollutants in laboratories has provided data on animal susceptibility, which in some cases can be applied to the study of man. It is believed, therefore, that well-integrated observations and experiments on animals both in the field and in the laboratory will be very helpful in discovering new information on the human effects of air pollutants.

3.3 Effects on plants

The chief concern in regard to the effects of air pollution on plants stems from the opportunity afforded for correlation with effects on human health. It cannot be denied that damage to crops *per se* is important, but it is not significant within the terms of reference of the Committee.

Studies of the effects on vegetation are at a relatively advanced stage. As a result, observations by exposure of selected plant species can provide information not only on the chemical nature of the air pollutants and their concentrations, but also on the duration of exposure to these agents. It is, in fact, practicable to use specific plants as continuous indicators of pollution in many localities. It may be that in the near future it will be possible to use appropriate plant species as alarm signals of potential danger to health before clinical symptoms are noted. The use of plants also provides an index of cumulative effects even after the pollution has disappeared.

Another possible use of plants in air pollution investigations is for the study of plant enzyme systems, when such systems are similar to those of man. In this way, leads can be obtained to possible human reactions.

Both botanical and animal studies on the effects of specific air pollutants,

groups of air pollutants, and gross air pollution as it occurs naturally, should be carried on by competent personnel in many selected places in the world with the purpose of accumulating useful knowledge in the shortest period of time.

3.4 Economic and sociological effects

The time is now long past when the amount of smoke belching forth from the industrial stacks of a community, and the griminess of the atmosphere, comprised an index of prosperity. The smokiness was supposed to indicate that the local industry was operating full-blast and that therefore all was well with the community. We now know that such smokiness is unnecessary and, what is more, costly to the community.

Various monetary estimates of losses due to air pollution have been made, and all of them have been of a high order of magnitude. No one has yet included in such estimates the monetary costs of illness and deaths caused by such pollution, leaving aside the accompanying human misery. Among the monetary losses due to such illness and death should be included direct medical costs, lost income resulting from absenteeism from work, and decreased productivity.

Other costs of air pollution include the following:

(*a*) increase of travel costs and time of travel due to reduced visibility, together with increased risk of accidental injury in travel because of decrease of visibility;

(*b*) increase of costs of artificial illumination;

(*c*) repair of damage to buildings and other structures;

(*d*) increased costs of cleaning;

(*e*) losses due to damage to crops and ornamental vegetation;

(*f*) losses due to injury to animals of economic importance;

(*g*) decrease of real-estate values;

(*h*) extra costs of manufacture because of pollution from outside sources;

(*i*) loss of the dust, vapour, or gas *per se*, which, if collected, might be of economic value.

In the last category it should be mentioned significantly that there is a tremendous loss caused by the generally inefficient combustion of solid, liquid and, possibly, gaseous fuels.

The sociological importance of air pollution results largely from individual economic losses. If economic damage were reduced, the sociological gains would be significant. This, added to the effect of cleanliness of the areas, might tend to reduce the development of slums.

4. PREVENTION AND CONTROL

It should be stressed at the outset that it is not practicable in the present state of knowledge to provide at reasonable cost all the growing needs and amenities of modern life without causing some pollution of the air. At the same time it cannot be too strongly emphasized that much of the pollution which now exists could be prevented without undue cost, and sometimes even with a financial saving, by careful planning and siting of factories and dwellings, better design of equipment, and better operation of the equipment based on adequate training of management, executives and operators.

4.1 Sources of pollution

In most industrialized communities, the major sources of pollution arise from the production and use as fuels of coal, coke, and oil, either direct or indirect, to produce gas and electricity, for heating dwellings and other buildings, for industrial furnaces and processes, and for transport by rail, road and water. In addition, there is often serious local air pollution from special industrial activities such as petroleum refining, production of cement, iron and steel, non-ferrous metals, sulfuric acid, chemical fertilizers, and a variety of chemical and other materials, and the disposal of household and industrial waste materials by incineration.[1]

4.2 Reduction of amount of pollution

Pollutants from the use of fuels for heating and for the generation of power include smoke, grit and dust, and gases and vapours containing oxides of sulfur, carbon monoxide and oxides of nitrogen, and often complex organic or metallic compounds, particularly in the exhaust gases from internal combustion engines such as those powered by diesel oil or gasoline and used for transport.

It is certain that, on the basis of existing knowledge, much of this pollution could be avoided without undue capital expenditure. Smoke, for example, is the visible sign of inefficient combustion with consequent waste of fuel. By ensuring controlled provision of the air supplies for burning coal and oil in industrial boilers and many other furnaces, there should be little or no smoke and a consequent saving of fuel for the same service. With the smaller domestic heating-appliances it is not, so far, economically practicable to burn bituminous coal without considerable smoke emission. The remedy in such cases is to replace the coal by anthracite, coke, oil,

[1] There is also serious pollution in some parts of the world from the use as fuels of wood and other vegetable matter, and of animal dung.

gas, or electricity. This may involve replacement of domestic heating-appliances in many areas.

Grit and dust are discharged from industrial furnaces burning coal or coke at high rates, especially with pulverized fuel burners. To remove much of the grit and dust involves the use of special equipment such as cyclone grit arrestors, electrostatic precipitators, scrubbers employing water, and filters. It is now becoming general practice to install such equipment at power stations burning large quantities of solid fuel.

Even with prevention of smoke and grit emission from industrial boilers and furnaces using solid or liquid fuel, the chimney gases are still polluting in that they contain oxides of sulfur derived from the sulfur in the fuels, oxides of nitrogen from the combustion process, and possibly other substances such as hydrochloric acid and complex carbon compounds. So far, no economic method of removing most of the sulfur from the coal or oil before combustion has been devised, nor has an economical and generally acceptable method of removing the oxides of sulfur from the chimney gases been developed. It may be mentioned that two processes of removing more than 90% of the oxides of sulfur from the chimney gases have been operated over several years at power stations in England. The one relies mainly on the alkalinity in large volumes of river water and produces an equal volume of liquid effluent containing calcium sulfate; the over-all cost is high, about 10 shillings (US $1.40) for the flue gas from each ton of coal burned. By the other method, the alkali is provided by hydrated lime; there is no liquid effluent but a large quantity of a sludge of calcium sulfate results as a waste product, and the over-all cost is as high as 17 shillings (US $2.38) per ton of coal. Experiments are in progress in several countries in attempts to find some cheaper and more satisfactory system.

Exhaust gases from internal combustion engines do not contain appreciable quantities of visible smoke if the engines are properly maintained and operated, which is by no means always the case. With present techniques, however, the exhaust gases include carbon monoxide, oxides of sulfur from diesel engines, oxides of nitrogen, and complex compounds of carbon from partially burned fuel and sometimes metallic compounds. Efficient maintenance and operation does reduce the quantity of pollutants discharged, but research is required to improve combustion while maintaining the flexibility of operation necessary in engines for transport vehicles.

Special processes such as the manufacture of cement, metals, and chemicals each require separate consideration. In many of them emission of smoke and the production of large quantities of grit, dust, noxious gases and vapours, sometimes accompanied by an offensive odour, are unavoidable with present techniques. The best available measures, however, should be adopted to keep down to the practicable minimum the amounts of the pollutants discharged. These measures include control of

the manufacturing processes and treatment of the effluents to remove much of grit, dust and other constituents before discharge to the atmosphere. Special arrangements are also necessary in dealing with some industrial wastes such as those from coal-mining and coal-cleaning.

4.3 Mitigation of effects

After everything economically practicable has been done to keep down the quantity of pollutants discharged to the atmosphere, the air may still be sufficiently polluted to be detrimental to health, unless other measures are taken to limit the discharges in an area or to ensure rapid dispersion and dilution in the air.

On discharge from a chimney, the dust and gases are carried by the wind and dispersed, but the amount and direction of dispersion are dependent on meteorological conditions that differ greatly not only from place to place but from time to time. Topography and the density, size and arrangement of nearby buildings also have their effect on dispersion, on the direction of the wind, and on the frequency, extent and structure of temperature inversion which in many areas often leads to a layer of stagnant air where the pollutants can accumulate for periods of hours and even days.

If dispersion is to be adequately achieved, the effective height of the chimney should be such as to ensure that under the least favourable meteorological conditions the concentration of pollutants in the air near ground level will not have a serious effect on health. The effective height of the chimney may be greater than the height of the structure as a result of the upward velocity and buoyancy of the discharge leaving the chimney. If, however, there is a high building near by, there may be a down-draught on the lee side drawing the discharge from the chimney to near ground level before there has been adequate dilution. Similar considerations apply to factories in valleys, illustrating the effects of topography.

4.4 Zoning

Indiscriminate siting of dwellings and factories discharging pollutants has produced conditions under which the people of certain areas are frequently exposed to harmful concentrations that could have been avoided by intelligent planning. Zoning of areas and siting of dwellings and factories should take into account meteorological, and particularly micro-meteorological, conditions. It is recognized, first, that there are other factors which the industrialist must take into account in selecting a site, such as facilities for supplies of raw materials, labour, transport, and markets for products, and second, that restrictions must be reasonable, otherwise many industries could not be carried on, and there would be consequent detriment to the over-all standard of living.

Some areas might well be designated " smoke control areas " where emission of smoke is prohibited. In such areas it is essential that the equipment should be capable of burning the fuel for which it was designed without emission of smoke, or that only smokeless fuels such as coke, gas or electricity should be used.

4.5 Instrumentation

All plant likely to emit undue quantities of pollutants if improperly operated should be equipped with appropriate control and warning instruments to guide the operators and inform the management.

4.6 Training

The training of management executives and operators in methods of keeping down the emission of pollutants from industrial operation is urgently required in many countries.

5. ADMINISTRATIVE ASPECTS OF AIR-POLLUTION CONTROL

The administration of a community air-pollution programme must be based upon the concept that clean air (not necessarily " pure " air) is attainable, and that the community may have clean air to the degree that it is willing to pay for it. The Committee further recognizes that the movement of air masses (and air pollutants) knows no jurisdictional boundaries of towns, counties, provinces, or states, and therefore, for the administration of an air-pollution programme to be effective, the area covered by such a programme may require extension beyond conventional governmental units. Finally, whereas the Committee acknowledges as a fact that a comprehensive air-pollution programme will include many facets of the problem in addition to the facet of control, for present purposes major emphasis is given to control.

5.1 Legislation

It is the opinion of the Committee that forms of legislation specially designed to make the control of the pollution of the air (by domestic, commercial, industrial and other activities) administratively workable are necessary and desirable whenever community circumstances are such as to produce a threat to health from current or anticipated atmospheric pollution.

5.1.1 *National legislation*

The administrative control of atmospheric pollution can be most effectively developed into appropriate law at a national level through the

action of a committee of persons representing public health administration, fuel usage, industrial hygiene, agriculture, science, industry and town planning. Such a committee would recommend the necessary legal instruments suitable to its unique country problems, and could call upon WHO for guidance.

It has been shown in other sections that reduction of atmospheric pollution can be achieved by the control of emissions (smoke, dust, fumes, noxious gases, etc.) from industries, public buildings and dwellings (1) by planning cities so that industries and other sources of pollution are so sited that the optimum degree of dispersal of pollutants is achieved before the pollutant is carried by air movement into zones of human residence, and (2) by radical change in the fuel supply or in the type of combustion unit for some of the small combustion units such as domestic fires or road vehicles. It therefore appears that legislation should be directed towards :

(*a*) the control of sources of pollution by specifying the types of industrial and other processes which should operate under supervision by control authorities, and the types of emission which should be kept to a minimum value ;

(*b*) the institution of town-planning practices in which due attention is given to the planning and zoning of industrial sites for the purpose of reducing air pollution, providing always that such action does not make the conduct of industry prohibitively costly or even impossible ;

(*c*) the provision of regulations controlling the types of fuel to be burned in installations where combustion emissions are not otherwise controllable.

In countries where it is applicable, legislation at a national level can be of the form in which the central government empowers local authorities to control emission of pollutants from domestic and commercial establishments and from various manufacturing processes, provides a schedule of those processes which should be so controlled, and defines the powers of the local authority in the exercise of its function. Alternatively, the legislation can give all the powers of control to the central government administration, laying down as before those processes to be controlled, and the functions and powers of the control officials.

It is also possible, and sometimes very desirable, to institute legislation which combines both these forms, so that local authorities which are well-enough equipped to carry out some of the control functions may do so, while in circumstances where the local authority has not the technical or administrative facilities for such work the whole responsibility is undertaken by the central administration. This form of legislation is flexible and allows for considerable modification in the administration of air-pollution control as a country develops its technology and the size of its cities.

5.1.2 *WHO action*

In all these items considered above, a WHO programme could be of considerable value in :

(*a*) analysing the various forms of legislation which have been developed in the USA, Great Britain and some continental countries, so that information would be available from which other countries could make sound decisions to suit the particular circumstances under which pollution control is to be undertaken ;

(*b*) arranging for consultations between those responsible for air-pollution control in new countries and administrators who have had experience in the working of pollution-control legislation in the more developed countries ;

(*c*) maintaining contact between senior control personnel in Member States, so that information about developments in one country of more successful control methods, or of new and hitherto unsuspected forms of pollution, or of a better appreciation of pollution hazards, may become available to all Member States as soon as possible.

5.1.3 *Standards*

When legislation is introduced for the purpose of preventing pollutants from being discharged into the atmosphere, it is natural for officials and those who are operating industrial plants to expect that there should be a standard of emission laid down, so that the official should have a test for compliance with the law, and the operator should be able to know when he is operating in a safe manner. In spite of this natural desire and of the need that the legislation should be precisely directed (so that there is no doubt as to what emissions and what atmospheric pollution will not be tolerated by the law), when it comes to establishing standards there is a danger in writing specific figures into the legislation because (*a*) industrial and technical performance is continually changing, causing standards to become outdated, and (*b*) a fixed standard for industrial operations can fail to take account of complexities in industrial development, so that a situation could occur where a rigid legal standard could result in the legal prevention of desirable industrial progress as the result of a technicality. To give an example, an industry could be developing a new production process which initially produced an emission greater than the standard. The control legislation might then prevent such an industry developing its process to the point where the emission could be reduced to a tolerable degree, and a possible valuable development would have been stopped.

Therefore, it is recommended that standards of performance for the purpose of controlling the emission of pollutants should not be written into legislation, but should be incorporated in the form of regulations,

capable of being altered by the administrative group, without necessitating return to the legislature for authority. The operative words " use of the best practicable means ", which are used in the control of the emission of pollutants in British factories, seem to establish a very important principle. The implication is that at any time that a lower limit of emission is found to be attainable in any one process, this automatically means that the standard of emission for that process has been lowered to the new low level which has been proved possible.

In the matter of smoke emission, the method of assessing the concentration of smoke being emitted has for many years been the estimation of the percentage blackness of the smoke (assuming that the particles which are being emitted are black). This percentage blackness, estimated by reference to the Ringelmann chart, or by means of some form of photometer which estimates percentage blackness and converts the reading to the figures 0-5 on the Ringelmann chart, is a standard which will probably be used for a very long time by air pollution control officials, but it is not an ideal standard, and in particular it is not applicable to coloured smoke, to smoke from low temperature fires, or to smoke which contains a high percentage of light-coloured ash. Thus, in drafting legislation, consideration should be given even in this case to the possibility that changes in the standard may become necessary. There is an opportunity for WHO to take action in keeping Member States acquainted with the latest position in regard to standards of emission.

5.2 Administration

The primary reason for the reduction of atmospheric pollution is a health reason, but the processes by which pollution is produced are metallurgical, chemical and engineering in character. Therefore, the responsibility for clean air is a public health one, but the implementation of the clean-air programme is technical. The public health official, the engineer and the scientist must therefore work in the closest co-operation, and the question of the most suitable type of organization for the enforcement programme arises.

Both at government and at local authority level the ideal situation would be one in which the administrative group was separate and distinct, with its interest wholly upon the air-pollution situation. However, there are few opportunities for such an arrangement, and it is usually necessary to place the administration of air-pollution control in a section of some already existing administration. It is considered by the Committee that it would be wise for the public health department to accept this public health responsibility. Serious efforts, however, should be made to see that control officials, from the executive level downwards, have the right technical training for their work.

A further consideration is that the enforcement official who does not have an intimate knowledge of the processes which produce the effluent to be controlled is liable to adopt a merely punitive attitude towards the industrialists over whom he has authority. Such an attitude, however, does not always result in the improvement in manufacturing methods which is usually necessary to produce a reduction in effluent.

It is, of course, true that written into the legislation there must be penalties for the ultimate coercion of the recalcitrant operator, but in many cases, as experience has shown, an operator is ignorant of the conditions which will reduce pollution, and what he needs is, first, an intimation that he is breaking the law, and secondly, an opportunity for discussion of the state of his plant and the measures which he may take to reduce the pollution. It has been found by a number of control organizations that one of their functions is to make available to one operator the information about methods for effluent reduction which have been devised by another (naturally with the consent of the second operator). Thus a control official who, by reason of his technological knowledge, commands the respect of the operators over whom he exercises authority is able to act as a consultant as well as a police official, and obtains optimum results in pollution reduction.

5.2.1 *Measurement*

Any control organization which wishes to establish an effective reduction in atmospheric pollution must of necessity make regular measurements of pollution density in the area in which it operates. It is well known that variation in meteorological conditions during the year, and even from year to year, can cause fluctuations in pollution density which are greater than the reductions which the control programme may produce. Therefore, if regular measurement is not undertaken, the control officials may be seriously misled about the value of the work which they are doing. In addition, they may have to meet adverse criticism from a public which does not see obvious results from their work.

5.3 Education and study

If legislation for the reduction of air pollution is to be effective, it must have the backing of public opinion, and this implies a knowledgeable public. There is therefore a need for the central authority to institute a programme of public education, explaining the general nature of air pollution, its adverse health effects, the ways in which the public can co-operate in the reduction of pollution, and the difficulties which are attendant upon any programme for producing clean air. When such an educational programme is effective the activities of the control authority are made considerably easier.

It is also important to realize that any administration which is concerned with a programme for the reduction of pollution should have a first-hand interest in some forms of study of the problem. It is often found that administrators consider that all that is necessary is to pass a law, and that clean air will result. It is found, however, that the administration of a law dependent on the application of technology is effective only when there is sound knowledge of the general scientific and technical situation. Therefore the setting-up of administrative control is liable to be ineffective if a measure of scientific study is not also undertaken.

5.4 Advisory council

A desirable step in the setting-up of air-pollution control at the national level is the establishment of an air-pollution advisory council which can maintain a supervisory watch on the various aspects of the country's effort.

This council, the members of which should include public health officials, industrial executives, scientists, engineers and persons experienced in public administration, should consider from time to time the results of the systematic measurements of air pollution which are being made. It should advise the government on the research which should be undertaken, on where financial assistance should be given for research work, and on the conduct of programmes of public education ; and in these and other ways it should give general assistance to the central administration.

The council should have close links with other administrative departments such as those for industrial hygiene, transport, housing, mining and industry (for air-pollution control impinges upon all these departments, and is affected by their activities), and as a voluntary body it should be able to see the air-pollution problem as a whole and in true perspective.

6. SUMMARY AND RECOMMENDATIONS

6.1 Standardization

1. There is at present a great variation both in terminology and in the units of measurements used in different countries to describe air pollution, its dispersion and its effects, which greatly hinders common understanding and interpretation of results among workers in this field. The standardization of nomenclature and of units of measurement commonly used in air pollution is highly desirable.

2. One step towards the reduction of air pollution is the objective evaluation of air contamination. Much can be accomplished by using simple instruments and methods for the measurement of dust-fall, smoke and the common gaseous contaminants. There is need for international standard-

ization of instruments, and of sampling and analytical methods, to provide accurate and comparable results as economically as possible.

3. The terms currently used to designate disease entities believed to be caused or aggravated by air pollution need to be clarified. Such disease entities should include chronic bronchitis and primary lung cancer.

6.2 Research

1. The ability of the atmosphere to disperse concentrations of pollutants varies tremendously. Some of the variations are governed by physical laws which are well known. Intensified research is needed, however, with the object of obtaining more information on the factors affecting air movement in localities of different types, such as the turbulent structure of the wind, and the low-level temperature and wind gradients.

2. On the basis of existing knowledge, much pollution of the atmosphere could be avoided without undue capital expenditure. Certain emissions from special processes, however, appear to be unavoidable with present techniques, and others can be reduced only at great cost. Intensified research is needed to obtain more information on methods of greatly reducing the quantity of pollutants discharged from special processes.

3. Intensified research is needed with the object of obtaining more information on the ultimate interaction and fate of pollutants, especially at times of temperature inversion and fog when the concentration of pollutants is likely to be greatest.

4. The effect of air pollutants on human health is influenced by a number of significant factors, among which may be climate, modes of living and other variables which differ in various parts of the world. Co-operative studies of morbidity and mortality rates need to be made for chronic bronchitis and primary lung cancer in countries for which the different significant variables can be accounted for and standardized.

5. Animal epidemiological investigations of air pollutants, both in the laboratory and in the field, should be intensified.

6. Additional centres for the laboratory investigation of the toxicity of specific pollutants, groups of pollutants, and grossly polluted ambient air, need to be established.

7. Many air-pollution problems are too complex for immediate and easy solution and therefore require expensive equipment and highly-trained investigators for their resolution. Institutions of higher learning and the appropriate international and governmental agencies should be encouraged to undertake research in solving these more recalcitrant problems.

8. Investigations of the use of indigenous plants or other biological entities as indicators of air pollutants should be intensified.

6.3 Collection and dissemination of information

1. With regard to those air pollutants that are known or suspected to be causes of harm to health, the current status of knowledge is inadequate to establish standards of what levels of concentration are safe for man. Information needs to be collected and collated on various recommended maximum allowable concentrations in the ambient air. Data need to be developed from further investigations of allowable concentrations.

2. Collection and dissemination of information should be promoted on limitations of the concentration of specific contaminants as discharged.

3. While there is much published information on many aspects of the air-pollution problem, more widespread dissemination is required of information based on experience of the effects of site-planning and zoning, height of chimney and velocity of discharge, in relation to local meteorological and topographical conditions and to density and type of factories and dwellings.

4. The air is the medium in which air pollution is diffused and transported. It is important, therefore, that there be a thorough study of local meteorological conditions in planning for the abatement of pollution in established communities, and for its prevention in the planning of new industrial and community developments. Systematic sampling of the area of pollution or potential pollution should be co-ordinated with the meteorological study.

5. Information on the costs resulting from air pollution in selected places in the world should be collected and disseminated.

6.4 Administration and legislation

1. Typical programmes and procedures should be developed, with lists of recommended instruments for communities of varying size and budget which are embarking on air-pollution control programmes.

2. Experience has shown that special legislation on air pollution is necessary to provide for a workable control organization, a firm indication of the conditions to be avoided or abated, and a basis for enforcement. As a step in drafting laws and regulations, it is recommended that national committees be organized, composed of representatives of various interests, including public health, fuel usage, industrial hygiene, agriculture, science, industry and town planning, to advise on the form and scope of legislation.

3. Though control must be backed by legal penalties, it is most effective when positive goals are defined and guidance is given to the industrialist.

It is accordingly recommended that, in the first place, educational measures should be used by inspectors and control officials in dealing with sources of pollution.

4. Particular attention is drawn to the desirability of establishing national air-pollution advisory councils to appraise the problem as a whole and to supervise all aspects of a national effort.

6.5 Training

1. In every phase and at every level of air-pollution control, means should be taken to provide appropriate and thorough training of officials, inspectors, technicians, and operators. Training may include such measures as specialized courses, technical meetings, individual instruction, and in-service training.

2. Many industrial processes, such as those at chemical works, can be operated with the minimum practicable emission of pollutants only by experts with a highly specialized knowledge of the processes concerned, and of the various aspects of the problems of air pollution. In this field it is recommended that the industrialized countries where these special processes are operated be encouraged to institute post-graduate or other special courses. They should also be encouraged to exchange information on these special problems.

3. The extent of air pollution by smoke and by grit and dust in many areas at the present time could be greatly reduced by the application of existing knowledge in designing and operating the equipment, particularly industrial boilers and furnaces burning solid and liquid fuel. At the same time there would result a saving of fuel of equal productivity or heating service. The full application of this knowledge will not be achieved without more widespread training of management, executives and operators, and dissemination of information.

It is accordingly recommended that systematic courses of training be instituted or developed, adapted to the different levels of staff and operators. Furthermore, those responsible for conducting such courses of training in different countries should have opportunities to exchange visits and to attend meetings of experts. Key personnel in air-pollution control programmes of WHO Member States, especially where programmes are not fully developed, should be given an opportunity of undergoing comprehensive training. In this matter WHO could be of assistance.

6.6 Education of the public

Any air-pollution control programme, to be effective, must have the backing of public opinion. Means should be taken to institute a programme

which will make clear to the public the general nature of air pollution, its adverse health effects, the difficulties which attend any programme for producing clean air, and the ways in which the public can co-operate in the reduction of air pollution.

6.7 Publication of a monograph

The Committee further recommends that WHO consider the publication of a monograph on air pollution, taking into account the documents prepared for the information of the committee and available from other sources.

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