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ENVIRONMENTAL POLLUTION AND ITS CONTROL

Report by the World Health Organization

ANNEXES

I. Research into environmental pollution

II. WHO international reference centres

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WORLD HEALTH ORGANIZATION

ORGANISATION MONDIALE DE LA SANTÉ

ANNEX I

RESEARCH INTO ENVIRONMENTAL POLLUTION

This document has been edited by Dr W. H. H. Jebb, Director of the Public Health Laboratory, Oxford, United Kingdom, and contains the collective views of several groups of experts on problems of pollution of air, water and soil. It summarizes their main conclusions and their recommendations on research needs.

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RESEARCH INTO ENVIRONMENTAL POLLUTION

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RESEARCH INTO ENVIRONMENTAL POLLUTION

Since 1963 a number of Scientific Groups concerned with various aspects of environmental pollution have met in Geneva and their recommendations are contained in "Microchemical Pollutants in the Environment" (MHO/PA/110.63) and reports to the Director-General by the Scientific Group on the Biological Estimation of Water Pollution Levels (MHO/PA/136.64), the Scientific Group on Biological Aspects of Microchemical Pollution of Water Systems (MHO/PA/143.64), the Scientific Group on Research into Environmental Pollution (PA/236.64), the Scientific Group on Long-Term Effects on Health of New Pollutants (PA/37.65), and the Scientific Group on Identification and Measurement of Air Pollutants (PA/66.19). The reports to the Director-General have not been published, nor is it intended that they should be published, but the names of the members of each of the Scientific Groups are given in Appendix I.

This report summarizes the main conclusions and recommendations of these Scientific Groups. Although the danger of pollution of the environment by radioactive material was well appreciated, consideration of pollution of this sort was very largely excluded from the reports of the Scientific Groups.

Introduction

The long-term effects on the public health of various contaminants in the environment are becoming more pronounced with the rapid changes that are taking place in connection with many of man's enterprises today.

Contamination of air, soil, food and water by inorganic chemicals and sewage has received attention in the past and no doubt will do so in the future. A problem which has received less attention is that which may follow the introduction into the environment of the organic chemicals man synthesizes for specific purposes.

Annually, hundreds of new organic chemicals are made; some of them are persistent substances; many of them are used on a world-wide scale. The chemicals in question include new plastics and plasticizers; synthetic detergents and solvents; additives to foods, fuels or alloys; and pesticides. To an increasing extent, synthetic chemicals are used in households, in appliances and furnishings, clothing and building materials. Many of them enter directly or indirectly into food, whereas more may reach surface and underground water supplies in addition to the atmosphere.

It is advisable to consider the different types of air, water and land pollution together rather than separately. There are many instances in which air, water and soil are polluted by the same type of waste. The dumping of molten slag from a steel blast furnace, for example, results in an immediate liberation of gases, the eventual pollution of streams by leaching from rainfall, and an alteration of the land surface that hinders subsequent beneficial use of the soil. There are other situations where the prevention of one form of pollution leads to another. Cyanides, for example, can be removed from the liquid wastes of electro-plating plants by acidification and aeration, but the result is pollution of the atmosphere by hydrogen cyanide.

Regulations designed for public health protection are sometimes based on the assumption that there is only one route of exposure for the substance in question. Such an assumption is generally false and it is becoming increasingly obvious that pollution exposures from all sources should be evaluated together.

Pollution of air, water or land may also affect the quality of foodstuffs adversely. Indeed the food chain is undoubtedly the major vehicle for the transfer of radioactive contamination and pesticide residues to man.

Pollution seems to be an inevitable consequence of modern industrial technology, rapid and convenient transport, and comfortable housing, but excessive pollution may interfere with man's health and his mental, social and economic well-being. The problem, then, is to determine the level of pollution which permits optimal economic and social development without hazards to health in its broadest sense. This can be achieved by the systematic application of existing knowledge, supplemented by results from well-chosen research projects.

Basic concepts in the evaluation of environmental hazards

In considering the long-term effects on health of low levels of contaminants in man's environment, some fundamental biological principles about the fate of these substances in or on the human body, and their effect on the different bodily functions must be discussed.

The problems are complicated and much basic general information is still needed, in addition to specific information for individual substances.

These effects might be divided into two groups:

(1) localized effects at the place of contact and entry, chiefly the respiratory and the alimentary systems, but to some extent, the skin and conjunctivae, and

(2) the effects after absorption and distribution inside the body.

Localized effects at point of contact and entry

At the place of contact absorption may be expected into the boundary zone of the organ, the outermost cells of which may be influenced in different ways. The normal biochemistry of the cells may show deviations leading to the release of substances which are transported by the circulation to other parts of the body, eliciting stress-reactions or interfering with metabolic processes elsewhere in the body. Or, local structural changes may occur. Local contact may also give rise to local nervous stimulation, or to central nervous system effects.

The local changes may give better protection to the organ or, by altering the conditions of absorption or penetration of foreign substances, may impair its natural defence mechanism.

Some facts are known about these contact effects but there are many gaps in the basic knowledge of the possible effects of long-term exposure. Little is known about the occurrence of specific protective substances.

Absorption and distribution

Absorbed chemicals interfere with the biochemistry of the cells only if some chemical reaction takes place. Storage of insoluble substances may limit the amount of pollutant available for such reactions. Storage may thus have the effect of excluding pollutants from vital biochemical processes. Some elements and radicals are chemically the same, or so like, the normal constituents that they are treated as such, and thus may disturb the normal biochemical processes, or the pollutants may be degraded or metabolized to substances which are then excreted. In some instances new toxic substances are produced inside the body.

If man did not have such biochemical mechanisms to take care of foreign substances entering the body, he would have succumbed to the many substances in nature that are foreign to him, but are known to penetrate into his body; many of these are harmful when absorbed in large doses. This agrees with the experience that up to now all toxic substances have been found in experimental animals to have - even with prolonged exposure - a minimal dose-rate, below which no detectable effect on health occurs within the normal life-span. The possible exceptions to this are causing mutagenic, teratogenic or carcinogenic substances.

Most toxicological research has been on the harmful effects of doses higher than these limits. For the evaluation of long-term effects, however, it is important to know much more about the biochemical reactions to doses below these limits. The normal enzymes, especially in the liver, may detoxify the potentially harmful substances. For example, during chronic intake of DDT in man, the rate of its conversion to the much less toxic DDE has been found to increase. Thus the problem of induction of adaptive enzymes is of importance. The identification of the enzymes capable of removing the atoms of chlorine and hydrogen from DDT and perhaps from other chlorinated organic compounds, as well as many other detoxifying biochemical processes, is an important field for additional research.

More basic knowledge about the general conditions of absorption, distribution, metabolism, storage and excretion, will permit the development of better criteria for public health regulations. The nature of the biochemical interaction between toxic agents and the limited number of normal enzymes and other cell constituents is not adequately understood. Such knowledge may well lead to general biological principles of value in setting up models for investigating the fate and interactions of new chemicals when they enter the human body.

The importance of normal variability

All biological processes and structures show variation within a "normal range" of variability. This reflects man's adaptation to his changing environmental conditions within the limits defined by his individual genetic make-up.

If the effects of long-term exposures do not exceed this normal variation, no harmful consequences need be anticipated. Health hazards need only be feared if the adaptation forces and defence mechanisms are overburdened or overstimulated.

Many agents, chemical and physical, confronting man provoke adaptive reactions. These biochemical and physiological reactions may either limit the capacity of the organism to adapt itself to the effects of other factors, or may stimulate the capacity for adaptation. These alternatives are important in the understanding of the health hazards of long-term exposure. Because of the importance of these adaptive mechanisms, experiments with combinations of pollutants and other stresses are much needed.

Effects on regulatory systems

Besides the effects of pollutants at the cellular level leading to biochemical deviations and structural derangements, there may be effects on the homeostatic regulation of the body, stimulation or inhibition of the nervous system, the regulatory hormonal system and the immuno-reaction of the reticulo-endothelial system.

Knowledge about these regulatory mechanisms is very scanty. Not every detectable effect in these processes has necessarily harmful or lasting consequences on health. Some reactions may be detectable now only because new techniques are providing more knowledge about the basic conditions of health and the processes of adaptation to the environment.

Other health-promoting measures may strengthen man's capacity to adapt himself to his changing living conditions. After all, man's ancestors have during the whole period of evolution adapted themselves to the changing conditions of life on this planet. Better nutrition, housing and environmental conditions might help man to bear the burdens of adapting to the physical and chemical agents to which he is exposed, but this, if true, must not be used as a reason for delaying the introduction of stricter requirements for air and water purity.

New approaches to research are needed to clarify basic concepts of environmental biology, by which is meant far more knowledge of the responses of living organisms to changing environments. Specialists in human biology have to collaborate with microbiologists, botanists and zoologists for this purpose. The fate of new chemical pollutants which contaminate the water or soil environment of many other organisms leads to an ecological disturbance in nature; observation of these effects is important for the understanding of human environmental biology.

Recent trends in environmental pollution

There can be little doubt that pollution of man's environment is increasing. It is not possible to give direct estimates of the amount of chemical pollutants in the environment at the present time. However, production figures for important groups of synthetic organic chemicals may serve as a guide. (See Figures 1, 2 and 3.) Information is available for Western Europe and the United States of America. As shown in Figures 2 and 3, for Western Europe the total production of chemicals increased more than two fold in the eight-year period 1953-60. However, during that time, the production of the chemicals of interest to us rose even more steeply: the output of petrochemicals increased eight-fold, that of the plastics industry almost four-fold, and that of pharmaceuticals almost three-fold. Comparative increases for the United States of America are four-fold for plastics, about three-fold for synthetic detergents and a little more than three-fold for pesticides. An important feature is the rapid increase in the United States production of insecticides, for which no comparative figures can be derived from available European reports. Western

European countries, however, do record a total production of synthetic detergents in 1960 and 1961 that approaches the rate of increase and the total production for these years in the United States.

Not all of the increases recorded in Figures 1, 2 and 3 would affect the respective environments. There was exchange of chemicals between the two continents and exports to other parts of the world. Nevertheless, it is obvious that among the great changes of the past decade, the production of chemicals - and in particular synthetic organic chemicals - is important. There is therefore good reason why we should consider the possible impact of these chemicals upon the environment of man and man himself.

Air pollution by smoke is declining in developed countries as a result of increased efficiency of combustion and the substitution of oil or natural gas for coal, whereas concentrations of some of the newer pollutants, such as those from motor cars, are increasing. In developing countries where rapid industrialization and urbanization are leading to an increased use of fuels, combustion equipment and industrial chemicals, a concomitantly rapid growth of pollution problems may be expected.

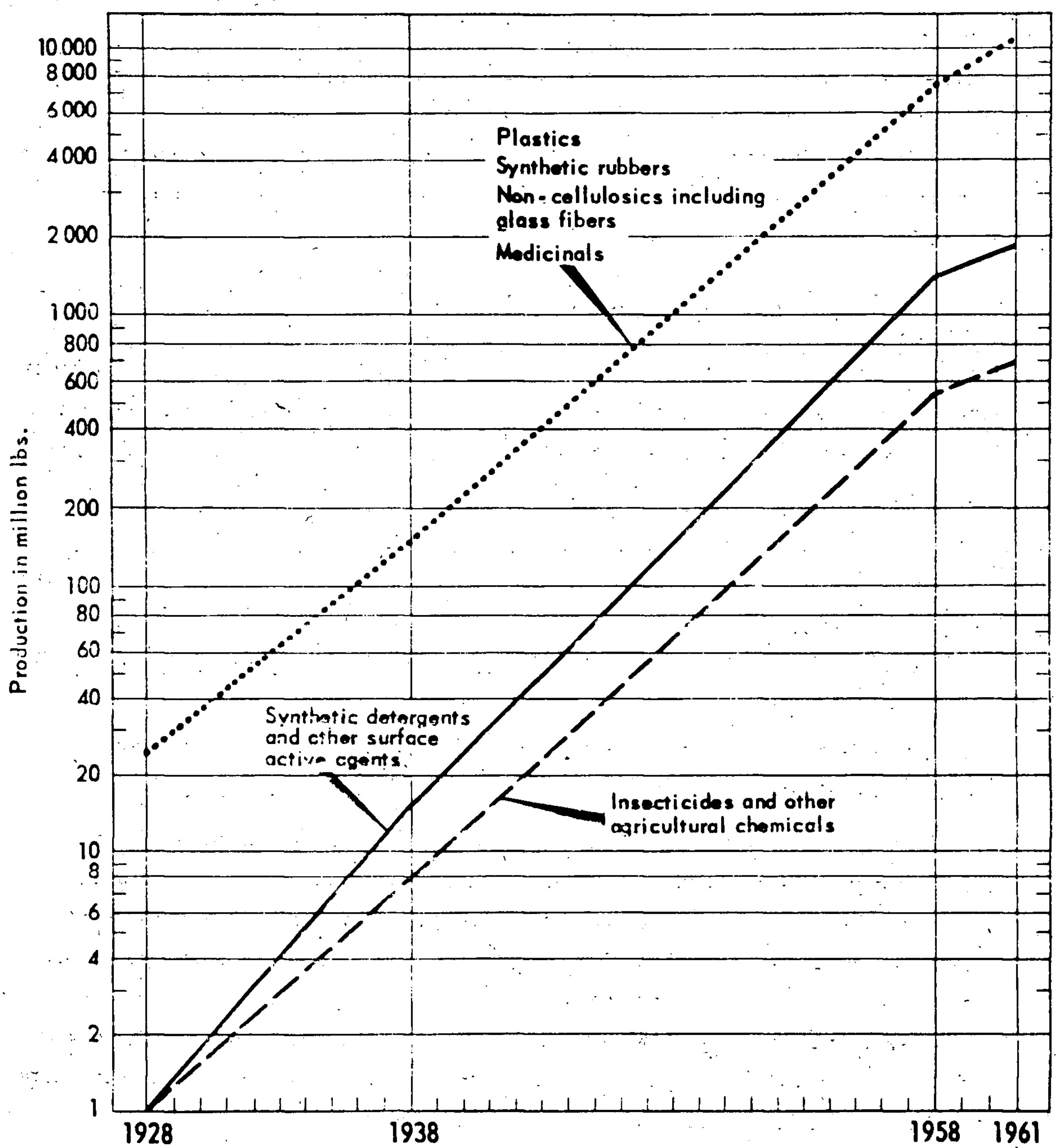
With the great increase in the use of motor vehicles, the problems caused by pollution from exhausts have arisen in many major cities. The unexpected and complex problem of photochemical pollution, first noted in Los Angeles, has been observed in other cities which have a sufficient concentration of motor vehicles, stagnant air, and an intensity of radiation of short wavelengths to promote photochemical reactions.

The pollutants primarily emitted by motor vehicles - hydrocarbon vapours and nitric oxide - are not harmful at the concentrations normally found in town air unless they take part in photochemical reactions. Nitric oxide in low concentrations is slowly oxidized in the ambient air to nitrogen dioxide, but the reaction occurs more rapidly in the presence of hydrocarbon vapours. The risks to health from nitrogen dioxide are greater than those of equivalent concentrations of nitric oxide, but more work is needed to assess the concentration at which nitrogen dioxide affects the lungs.

Two pollutants, carbon monoxide and lead, emitted by motor vehicles, are also of concern, although they take no part in photochemical pollution reactions. Carbon monoxide combines reversibly (with a biological half-life of the order of three hours) with the haemoglobin in the body and prevents oxygen transport. In many cities pollution by exhaust gases is sufficient to inactivate from one to six per cent of the haemoglobin in all members of the exposed population.

FIG. 1

GROWTH IN PRODUCTION OF SYNTHETIC-ORGANIC CHEMICALS IN USA

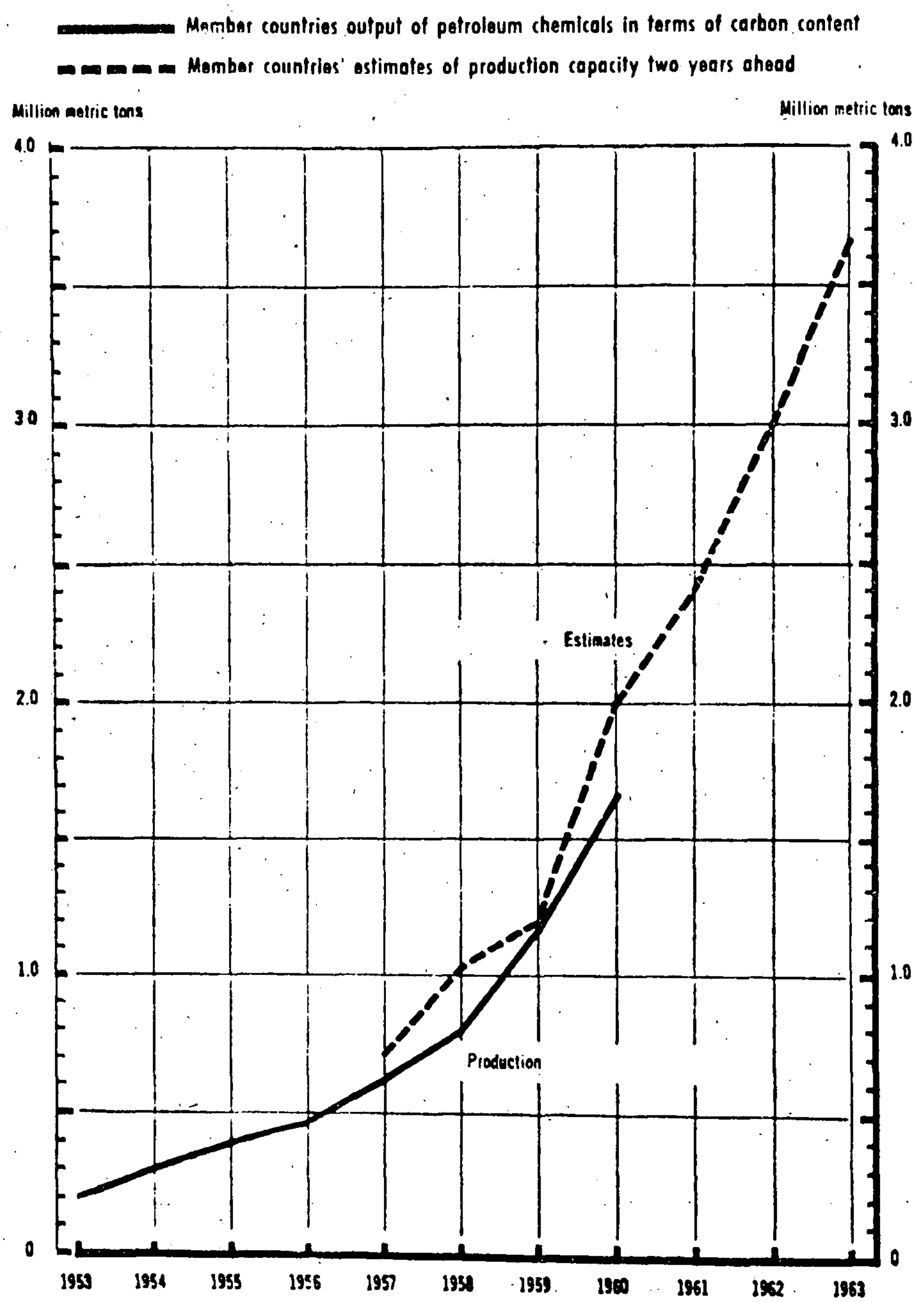


(Data from U.S. Tariff Commission)

WHO 3134

FIG. 2

DEVELOPMENT OF PETROLEUM CHEMICAL PRODUCTION FROM 1953 TO 1960 AND ESTIMATES OF PRODUCTION CAPACITY TO 1963 IN WESTERN EUROPEAN COUNTRIES

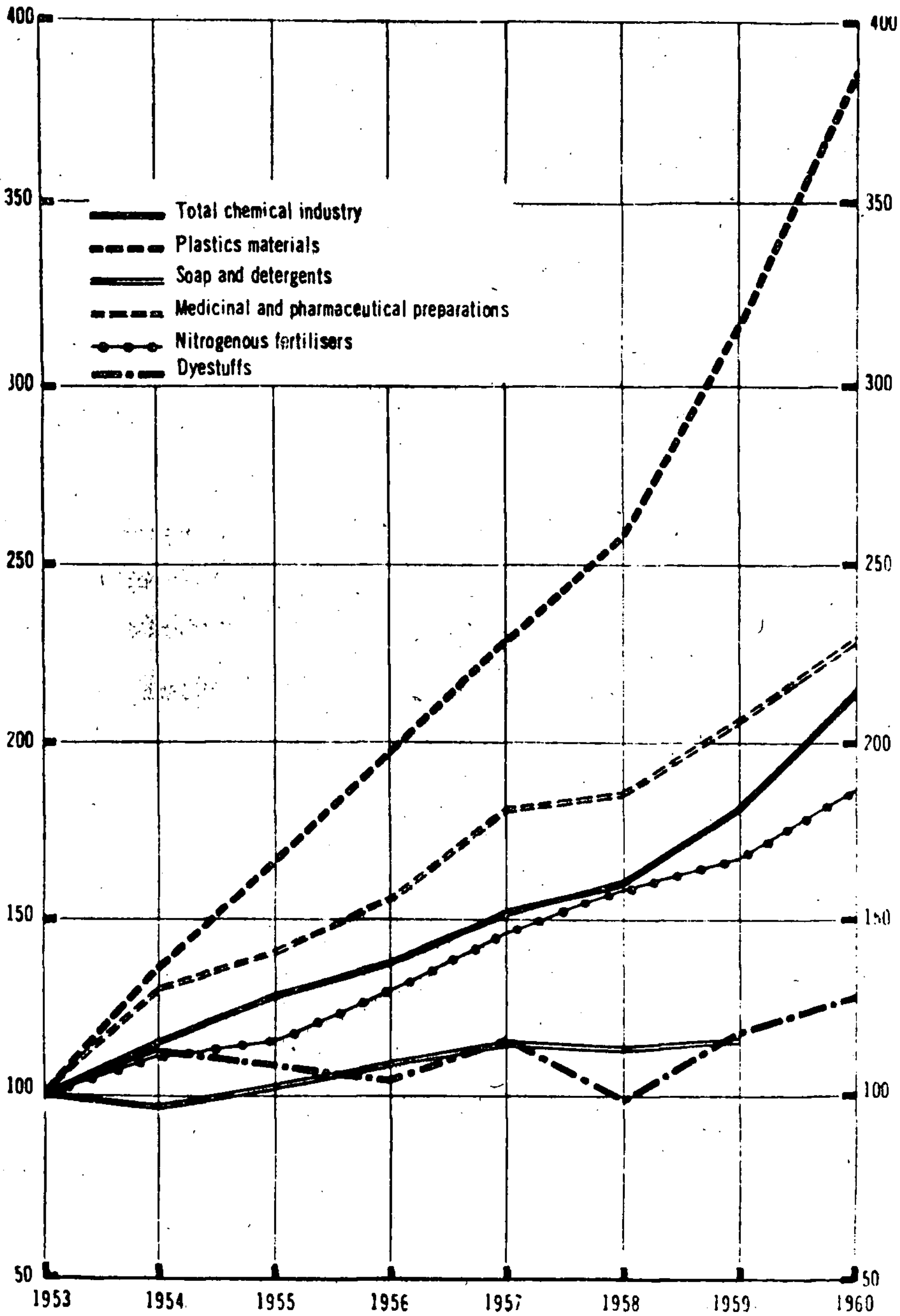


(From The Chemical Industry in Europe 1960-1961, OECD)

WHO 3221

FIG. 3

DEVELOPMENT OF THE CHEMICAL INDUSTRY AND CERTAIN BRANCHES IN WESTERN EUROPE
1953 = 100



(From The Chemical Industry in Europe 1960-1961, OECD)

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Inorganic lead is emitted from the breakdown of tetraethyl lead which is used as a motor-fuel additive. The air of Los Angeles contains up to twice as much lead as that of other large cities.

In some developed countries legislation has been introduced regulating the discharge of industrial wastes to sewers and water-courses, but many developing countries undergoing rapid technical development lack adequate numbers of trained personnel, equipment and other facilities for the assessment and control of environmental pollution.

Vehicles of transfer of pollution to man

Although it is artificial to draw a distinction between polluting substances reaching man by way of air, water or food - since, for example, a single chemical sprayed on a crop may be inhaled, may alight directly on the skin or conjunctivae, may be washed into a water-course and subsequently drunk, or may be ingested in the sprayed crops or in fish which have been present in the water-course - it is convenient to make such a distinction for purposes of description. Most environmental pollutants, however, commonly reach man by one of these vehicles rather than the others, and they will be considered separately here.

I Air Pollution

Purposes of air pollution investigations

a. Principal purposes of air pollution measurements. The fouling of the atmosphere by the waste products of man's activities, particularly in urban communities, is rapidly increasing throughout the world. Although each air pollution problem must be evaluated on the basis of its own individual characteristics, sources of pollution, in a general sense, may be classified into several broad categories: the combustion of coal and oil in domestic and industrial heating and steam -generating plants, motor vehicle emissions, industrial effluents, and miscellaneous commercial and community activities such as the burning of solid wastes, solvent losses, pesticides and agricultural chemicals.

b. Preliminary assessment of a problem. Before complicated methods are used to measure the concentration of pollutants, the nature and magnitude of the problem must be assessed. Many pollutants are invisible and odourless, and some of them can be very dangerous. Nevertheless, for preliminary assessment as to whether a problem exists, a careful inquiry about local sources, including fuel usage, suspected effects, inspection of the buildings and crops in the area, observation of plumes and the use of the sense of smell may be of great value. These procedures may not, however, provide assurance that there is no pollution problem, not only because some pollutants cause no effects detectable by sight or smell, but also because concentrations and reactions may be influenced by unusual meteorological conditions not present during the preliminary assessment. At this early stage of an investigation concentration of a gross and easily measured pollutant may often be taken as an indicator of the amounts of some other pollutant, the estimation of which is more difficult or expensive to carry out, for example if the main pollutant is coal smoke the assessment of smoke may give a rough indication of the concentration of polycyclic hydrocarbons.

c. The identification of sources of pollutants. Surveys involving the measurements of the concentrations of individual pollutants may be needed in order to identify with certainty the sources which are responsible. These problems may be difficult; an example is that of distinguishing between the contributions made by coal combustion and motor vehicles. Here both sources may emit polycyclic hydrocarbons and carbon monoxide, and care must be taken to select for measurement indicator pollutants emitted from one or other source alone, for example, by calculations ratios of concentration of individual hydrocarbons by which the source may be identified.

d. Assessment of effects on health. Public health authorities in many parts of the world use measurements of air pollution to assess the magnitude of their problems in comparison with those in other areas. For these purposes a network of sampling stations may be established and observations made at fixed intervals for prolonged periods. In some surveys intermittent sampling at different sites is used according to a predetermined statistical design, but whatever the procedure adopted it should be capable of yielding a reasonable estimate of the distribution of pollution exposures affecting the population within the survey areas and of demonstrating the variations that occur with the seasons and with atmospheric conditions.

Maximal values may be more relevant than mean concentrations, especially in studies of the acute effects of pollution; for this purpose observations must be made over periods of not more than 24 hours, and continuous or hourly records may be valuable. In studies of the development of chronic diseases and of long-term effects it is necessary to use in addition mean long-term concentrations of pollution. A relatively simple sampling procedure has sometimes been used by which material is collected continuously over periods of a month or more at a time.

Exposure of individuals or population groups to specified pollutants is usually estimated from the results obtained with fixed samplers placed in the areas where people live or work. This procedure is usually satisfactory in urban environments where the concentrations of pollutants do not fluctuate very rapidly with time or place, but in some cases "personal" samplers may be required to obtain a satisfactory measure of the exposure of individuals, especially in their homes.

It must be recognized that health may be affected indirectly by impairment of well-being. For example, particles big enough to be deposited rapidly and too big to be inhaled and cause pulmonary disease, may soil fabrics, buildings and paintwork and may thus indirectly affect health by causing annoyance; bad smells and eye irritation may not cause demonstrable pathological changes, but they affect well-being to a serious extent.

e. The assessment of the relation of weather to pollution. Frequent and widespread measurements of pollution may be needed in order to assess the effects of atmospheric conditions on the dispersion of pollutants or the chemical interaction of individual contaminants. Probably the most notorious examples of this type of problem are the Los Angeles photochemical pollution and the British smoke-polluted fog. In both instances reactions that occur between pollutants are greatly dependent on meteorological factors and only by careful measurement can be mechanisms by which secondary pollutants are formed be elucidated.

f. The assessment of the effects of control measures. In many parts of the world air pollution is regarded as an intolerable nuisance and measures to abate it have been taken. Obviously the effect of the implementation of "clean air" regulations can only be assessed by studying the results of measurements made systematically over a long period and in many places. All too often use is made of short series of measurements to assess their effect; because pollution is so often dependent upon meteorological variability care must be taken to ensure that no false conclusions are reached by careless interpretation of short series of measurements.

g. The use of measurements of pollution for planning and economic developments. If pollution of the air is to be avoided rather than abated, plans must be made so that power stations, industrial plants and domestic sources of pollution do not "overload" the air. In many parts of the world careful surveys of concentrations of pollution are made before places are developed for industrial use or as areas of high population density. This practice has much to commend it, and the development of many pollution problems is avoided by the recognition of the importance of air pollution in town planning.

h. The development of air quality criteria or guides. People may wish health agencies to state what they consider to be tolerable or intolerable concentrations of pollutants and to draw up regulations under which these limits may not be exceeded. WHO is attempting to establish such criteria and guides, along lines recommended by the WHO Expert Committee on Atmospheric Pollutants.[1] The need for widespread and frequent measurements of individual pollutants and combinations of pollutants for this purpose is obvious.

i. The measurement of pollution for research purposes. Seldom, if ever, is pollution simple; compounds often react in the air after emission. The structure and size of particles and droplets may be complex and may vary with the temperature and the humidity. Research into these matters is in its infancy and many measurements of many pollutants will be needed in order to study the changing nature of pollution.

Sampling principles and procedures

In regard to air pollution, "sampling" means the collection of a certain volume of air or a certain quantity of one or more pollutants for the purpose of determining the atmospheric concentration of the pollutants.

Sampling usually precedes analysis and there may be a time interval of some length between the two operations. However, when it is desired to start a study of air pollution and it has been decided that the survey should concentrate on specified pollutants, a list of the analytical methods available, together with the corresponding sampling method or methods, should be drawn up. By matching analytical and sampling methods to the needs of a study the basis for a definitive choice is obtained.

a. Principles for the selection of a sampling method. The choice of technique depends on many factors: firstly, on the purpose of the measurements, then on the type of effect in which one is interested, and on the appropriate period for averaging, and on the method of reporting results.

[1] Wld Hlth Org. techn. Rep. Ser., 1963, 271

Another factor in the choice of a sampling technique is the limitations imposed by the sensitivity and specificity of analytical techniques.

Important considerations are simplicity of the sampling method and the availability of apparatus which is strong, cheap, portable and compact and which preferably does not require any source of energy at the sampling point but yet produces the greatest possible quantity of data.

Finally, it must not be forgotten that the sampling method must be effective; that is to say, it should obviate any loss of the pollutant at the moment of collection, and any transformation thereafter by mutual reaction of antagonistic pollutants or by disappearance of a pollutant as a result of adsorption, volatilization, agglomeration or shattering of the particles. It should provide a sample representative of the air as inhaled at the sampling point.

b. Sampling procedures. As regards duration of sampling period, two techniques are currently employed: (a) short period or "spot" sampling, and (b) continuous sampling for the measurement of maximal and average concentrations over definite time intervals. Spot samples are usually collected for specific purposes over varying periods of less than 30 minutes to several hours. Such samples have restricted value except where only minor changes in concentrations at particular periods of the day occur as a result, say, of the traffic density or where spot sampling is conducted for the purpose of random checks on pollution at many points. In general, pollution levels fluctuate widely in accordance with prevailing meteorological conditions and are influenced by such factors as the topography, mass emission rates, temperature, velocity and density of stack gas, height of stacks, distribution of sources and distance from sources down-wind. It is obvious, therefore, that spot sampling cannot be employed to characterize fully the nature and magnitude of an air pollution problem. The determination of maximal concentrations of a pollutant over short intervals is limited by the time constant of the sampling or continuous recording instrument.

Systematic studies of the nature and extent of pollution in the ambient air to obtain data for epidemiological surveys, for evaluating the potential hazard to man, animals or vegetation, and for control programmes, usually require continuous sampling techniques. Maximal and average concentrations over definite time periods can be read or calculated, depending upon the duration of the sampling cycle. Within a given cycle, peak concentrations over relatively short periods can also be determined. The instrumental techniques, however, may lack specificity and the data must therefore be checked frequently by calibration and by other more specific analytical methods. Where continuous automatic instruments cannot be employed, the samples can still be collected continuously by appropriate chemical absorption or filtration of measured air volumes in a sequential fashion and analysed subsequently.

It is recommended that for international comparison of routine sampling measurements the period of collection should be standardized so that a short-term sample would be defined as one collected during 30 minutes and a long-term sample as one collected during 24 hours.

The physical and chemical properties of pollutants often influence the technique to be adopted. Thus, in the case of gaseous pollutants, the samples can be collected in glass or metal vessels previously evacuated or in plastic bags inflated by a hand-pump or an electro-mechanical membrane pump; by aspirating air through a cold trap by which gaseous pollutants with a high boiling point are retained; by dissolving in an appropriate solution; by transformation, using an appropriate, and if possible selective, liquid reagent, into a compound that is easier to titrate or detect colorimetrically; by adsorption on to a suitable solid adsorbent, possibly at low temperature, the pollutant being liberated by subsequent treatment; or by reaction with a solid reagent spread over an inert surface in a detector tube or on filter paper. In this latter instance the reagent chosen should be such that the pollutant to be determined causes a change in colour, which can be used directly for measurement.

For liquid or solid pollutants, the following methods may be used; aspiration through a filter of known porosity, that retains ordinary and radioactive suspended matter; impaction of particles hurled at great velocity against a solid partition, in the presence or absence of a liquid; cyclone centrifugation, by means of which suspended matter of relatively large diameter is retained, possibly followed by filtration to remove small particles which the cyclone has not stopped; and thermal or electrostatic precipitation.

The various procedures have their advantages and drawbacks, which must also influence the choice of the sampling technique.

Sampling methods for direct analysis call for equipment that is generally expensive and must be set up for use at a single sampling site. Consequently the number of sites cannot be multiplied without increasing the equipment and thus the costs involved. On the other hand, by means of direct analysis the daily trend of pollution at a given place can be determined. The method is especially valuable when it gives, either directly or by integration, successive means over a given time interval.

Sampling methods for delayed analysis have the advantage that in this way a large number of sampling sites can be kept under surveillance with only one expensive analytical installation. On the other hand, sampling is almost instantaneous at each site, which excludes the possibility of establishing means in relation to time in the sense that these have been defined above. Furthermore, surveillance of a large number of sampling sites poses the problem of the division of the area concerned into units and of the most suitable way and time of visiting each of the sites chosen in these units.

Measurement of air pollution

Air pollution nomenclature. The need for agreement on the use of well-defined and precise terms to describe phenomena connected with air pollution in different parts of the world has been pointed out by a WHO Expert Committee on Atmospheric Pollutants.[1] At present the use in technical literature of imprecise words such as "smog", "smaze" and many others to describe the nature, origin and constitution of air pollution and the influence of associated atmospheric or meteorological factors creates confusion.

Units. The interchange of the results of air quality investigations would be made easier if a common nomenclature, consistent units and uniform methods were adopted internationally. A brief review of the problem was made at the 1963 Inter-Regional Symposium on Criteria for Air Quality and Methods of Measurement. A number of units for the expression of the results of sampling and the analysis of particulate and gaseous contaminants and of related environmental factors are recommended in "Guide to the Selection of Methods for Measuring Air Pollutants" (See Bibliography).

The kilogramme-metre-second-ampere system should be employed for expressing the results of air pollution measurements. The concentration of pollutants in terms of this system should be reported as mass per unit volume at a standard or reference temperature and pressure. There is general agreement that the standard pressure of 1013.25 millibars (equal to 760 mm Hg) and temperature of $0^{\circ}C$ should be employed. Although in many instances the correction to standard or reference gas conditions may not be justified for local purposes because of inherent errors or limited accuracy of measurements, it is essential that the

[1] Wld Hlth Org. Techn. Rep. Ser., 1963, 271

TABLE I

RECOMMENDED UNITS FOR AIR SAMPLING AND ANALYSIS

Item	Recommended units	Alternative or derived units	Symbol
Suspended particulate matter	Milligrams per cubic metre	Micrograms per cubic metre	mg/m^3 µg/m^3
Gases or vapours	Milligrams per cubic metre[a]	Micrograms per cubic metre parts per million by volume	mg/m^3 µg/m^3 ppm
Gas volumes	Cubic metre at standard conditions[b]		m^3
Volume emission rates	Cubic metres per sec		m^3/sec
Velocity	Metres per second		m/sec
Air sampling rates	Cubic metres or cubic centimetres per second	Litres per minute	m^3/sec cm^3/sec l/min
Temperature	Degrees centigrade		°C
Time of day	00.00 to 24.00 hours		hr
Pressure	Millibars	mm of Hg[c]	mb mm Hg
Visibility	Kilometres	Metres	km m
Light - transmission reflectance	Per cent. transmittance Per cent. reflectance		% T % R
Particle size	Micron (10^{-6}m)	Micrometre	µ µm
Wave length of light	Millimicrons (10^{-9}m) = nanometre	Angstrom (10^{-10}m)	mµ Å nm

[a]For substances of known molecular weight ppm by volume may be converted to mg/m^3 by multiplying by $\frac{\text{molecular weight}}{22.4}$.

[b]Standard conditions refer to 0°C and standard pressure 1013.25 millibars (760 mm Hg).

[c]mm of Hg x 1.3332 equals millibars at standard temperature, 0°C.

temperature and pressure conditions should be reported for all measurements involving comparative or precise studies. Normally, the concentration of air pollutants in this system should be expressed in milligrams per cubic metre.

Some substances occur in the air in such low concentrations that the recommended mass concentration unit (mg/m^3) is greater by a factor of 1000 or more than the mass actually existing in a cubic metre of air. Polycyclic aromatic hydrocarbons and analogues, potentially carcinogenic, as well as some highly toxic compounds are in this category. In such instances, the concentration may be expressed as micrograms (μg), nanograms (ng) or picograms (pg) per cubic metre.

Computation of the results of atmosphere sampling and analysis would be simplified considerably and the data rendered more easily available for comparison if expressed in the units recommended in Table I. It will be noted that for many items listed in this table alternative or derived units are given along with the recommended units. The choice is one of convenience in reporting data, mainly to avoid the use of cumbersome decimals.

Analytical methods

The report "Guide to the Selection of Methods for Measuring Air Pollutants" (See Bibliography) reviews extensively many of the analytical methods currently in use. Further research is however required into analytical methods.

a. Background. Analytical methods for measuring air pollution range from very simple chemical techniques to highly complex procedures using elaborate instruments. The type and number of analyses which may be required depend on the purposes of the study. A simple standard analysis may be repeated thousands of times and need many man-hours. On the other hand, the analysis of a single sample may require the efforts of a research team for a number of days or weeks.

b. Simple methods. One of the goals of research into the development of analytical methods is to provide simpler techniques, not only to reduce the time taken for analyses but to allow their use over a wide range of locations, both field and laboratory, by personnel ranging in qualifications from voluntary co-operative workers to trained chemists. Simple methods are particularly desirable for the common pollutants measured routinely in network operations or extensive long period field studies.

c. Sensitive methods. Many existing or potentially useful methods for air pollution studies are insensitive; this is particularly true for many methods useful in industrial hygiene. To overcome this deficiency, more elaborate sampling equipment may often by required, or additional time and equipment for analysis in the laboratory. While sensitivity (ability to detect small amounts) is very important in air pollution studies, high precision (the ability to distinguish between two measurements of nearly the same magnitude) is not always important. Usually precision of $\pm$ 20 per cent. suffices.

At the present time, methods that are both simple and sensitive are lacking particularly for use in the field. For more complex studies, e.g., the determination of ions or compounds by size classification, particularly in the sub-micron size range, the need for sensitivity is paramount.

d. Specific methods. Air pollutants of interest are usually present in air in small quantities often in combination with other substances. These additional substances pose problems if they interfere with the analytical techniques used for a pollutant of special interest. Many of our analytical methods have not been investigated in sufficient detail to enable us to discern the nature and extent of the interferences in various polluted atmospheres, or how to overcome them or correct for them.

e. Organic pollutants. New substances from the chemical and metallurgical industries pollute the air. Studies of the effects of new organic pollutants would be facilitated by the development of sensitive and specific methods for their identification and measurement. This may require a substantial effort and expenditure of funds.

f. Gas-aerosol relationships. The role of particulate matter in the possible potentiation of effects of gases on the respiratory system is a topic needing extensive investigation and clarification. Present techniques are grossly inadequate for an understanding of the absorption/adsorption relationships between common gaseous pollutants and particulate air pollutants and their subsequent elution in the respiratory system. The solution of this problem may require the use of advanced physical techniques and chemical analytical methods.

g. Chemistry of the sulfur cycle. The chemistry of the sulfur cycle in the atmosphere is of widespread interest, because sulfates may potentiate the effects of sulfur dioxide. Methods of determining the fate of sulfur compounds in the atmosphere are needed particularly in the sulfur dioxide/sulfur trioxide/sulfate conversion. Other sulfur-containing compounds of interest are inorganic and organic sulfides, mercaptans, sulfites, etc.

h. Photochemistry. Emissions from automobiles and from the combustion of other fossil fuels are two important sources of atmospheric pollution. In order to extend our knowledge of the effects of these pollutants, studies are needed to further define atmospheric photochemical reactions involving organic compounds. The development of analytical methods is an integral part of such studies.

i. Tracers for meteorological research. A limitation on the use of tracers for atmospheric circulation studies, particularly over long distances and for extensive time periods, is the lack of non-toxic tracer materials that are stable over the normal range of the ambient air temperature, humidity, solar radiation and precipitation. Of greatest promise in this search are polar compounds capable of being detected in very minute traces by the use of such analytical techniques as gas-liquid chromatography with electron capture detection.

j. Recent developments in analytical chemistry. During the past 10 years, developments in analytical chemistry have provided unusual opportunities for greater sensitivity and specificity in air pollution measurements. Gravimetric and titrimetric methods have been supplemented to an increasing degree by spectrophotometry, infra-red spectrometry, coulometry, gas-liquid chromatography and others. These newer methods are already widely used, yet none of the present air pollution reference books include more than brief mention of spectrophotometric methods and little, if any, mention of the others. It is important that air pollution studies be conducted with the best analytical methods available and that special attention be paid to the purity of the reagents used. The simplicity, sensitivity, reliability and economy of many of the newer methods should result in significant advances in the study of air pollution. It is important to recognize that the high cost of certain new equipment may be justified by the results obtained and the savings in manpower costs.

Organic pollutants can now be identified and determined in a most efficient manner through the use of gas-liquid and other types of chromatography. A relatively few years ago, only a limited number of organic compounds could be determined. Hydrocarbon indices could be measured on a non-discriminatory basis. With the introduction of gas-liquid chromatography, the constituents of complex mixtures of gaseous organic compounds can be separated and individual constituents identified and determined. With programmed temperature and other types of chromatography, high molecular weight organic particulates can be analysed.

Infra-red spectrophatometry by itself, or following chromatographic separation, has proved useful for the study of individual air pollution problems. Infra-red methods may be used not only in the identification and estimation of organic pollutants for research, but also in monitoring systems, e.g. for carbon monoxide.

In special circumstances, thin layer chromatography, mass spectrometry, fluorimetry, phosphorimetry and polarography can be used in air pollution problems. These techniques so far are used only occasionally for routine measurement, but they are important as research tools for special problems. For example, complex mixtures of hydrocarbons may be difficult to analyse by use of gas-liquid chromatography alone. Thin layer chromatography can then be used as an initial step in which preliminary separations are obtained and the separated components can then be injected into a gas chromatograph for final separation, identification and estimation. Likewise, mass spectrometry can be used to identify materials that have been separated chromatographically. Fluorimetry is often used, particularly in conjunction with special observations made at very low temperatures. Likewise, phosphorimetry provides a powerful means for making identifications and determinations when only minute amounts of material are available.

The study of inorganic pollutants is now made easier by the availability of new techniques, including new reagents and new instruments. One of the older analytical methods, flame photometry, is being more widely used than in the past because of new methods of excitation. Originally the flame photometers were used only in determining alkali metals or alkaline earth metals. Better methods of excitation have made it possible to use flame photometry for other determinations, such as the estimation of magnesium, zinc and lead. The technique is remarkably sensitive and quite reliable, particularly when interference effects are not serious.

Of special significance is the recent introduction of atomic absorption spectroscopy. This technique is generally as sensitive as, or more sensitive than, either flame photometry or emission spectroscopy. More important than the sensitivity is the fact that atomic absorption spectroscopy is inherently specific. The technique is simple and the equipment relatively inexpensive at least when compared to the cost of emission spectroscopy. The atomic absorption of radiant energy by atoms at the ground state serves as a means of identification comparable to the emission of radiant energy by atoms at excited states. Absorption serves as a means for quantitative estimation of minute amounts of metals.

Recent developments of specific selective and sensitive reagents or reactions make possible the detection and determination of many substances of interest in air pollution work. The great sensitivity made possible by the use of many of the reactions permits determinations to be made in the microgram and nanogram range. Specific or highly selective reactions enable direct measurements of pollutants to be made, often without need for concern regarding possible interference. Spectrophotometric equipment, upon which many of these tests depend, is fortunately becoming widely available.

The recent development of ring-oven methods offers certain advantages over spectrophotometric techniques, particularly for analysis of relatively small samples collected over a short period of time. The ring-oven is a simple, inexpensive apparatus which permits separation, concentration and use of chemical means for the detection and determination of various substances at microgram and nanogram levels. Ring-oven methods offer great promise for the study of airborne particulates because they are so sensitive, reliable and convenient. Results can be obtained in which the relative errors are not more than five to ten per cent., which are usually acceptable at microgram levels. Specific methods are already available for the determination of aluminium, beryllium, nickel, copper, iron, zinc, lead, cadmium, vanadium, antimony, selenium, phosphate, and sulphate. Additional methods are being developed.

k. Miscellaneous methods. Neutron activation is sometimes used where extremely minute amounts of material must be studied. This technique provides great sensitivity and reliability and is sometimes the only method applicable.

X-ray spectrometry sometimes provides special information and may be used as an adjunct to microscopical studies. The microprobe methods are particularly attractive for studying airborne particulates in special cases. Highly skilled technicians are required and the equipment is very expensive. The same comments apply to electron microscopy which is useful in the investigation of special problems.

Certain electrochemical methods have special applications in air pollution work. Coulometric titrations may be used where very sensitive and accurate methods are required. These methods are particularly attractive for continuous monitoring of air pollutants.

Recently automatic instruments have become available which are sufficiently sensitive for atmospheric measurements. These employ standard principles such as colorimetry, conductivity, fluorescence quenching and absorption spectroscopy.

Biological effects as indicators of pollution

Biological indicator systems have been of very great importance in indicating the harmfulness of pollution to human well-being. The effect on vegetation, for example of sulfur dioxide on alfalfa or lichens, of fluorides on gladioli, or of ethylene on the flower of the tomato plant, are specific and semi-quantitative, though an experienced plant pathologist may be required to differentiate the effects of pollution from those of plant diseases, climatic changes, or soil conditions. Effects of photochemical air pollutants on annual blue grass (Poa annua) and pinto bean (Phaseolus vulgaris) have been used to detect and estimate levels of ozone and peroxyacetyl nitrate in mixtures. In addition, biochemical studies on plants help in the study of the effect of pollutants on human biochemistry.

Man is, however, the ultimate biological indicator of air pollution hazards, and for at least one pollutant, carbon monoxide, the human body acts as an integrating sampler. The direct absorption of this pollutant into the blood from the lungs and the reasonably well-defined uptake and excretion rates permit the amount of carbon monoxide in the blood of non-smokers to be used at once as an index of exposure within the previous four to eight hours and as a numerical guide to the health hazard. By measuring accurately the amount of carbon monoxide in equilibrated expired air of exposed persons, the health hazard can be determined directly and simply with less difficulty than if the same measurement were made in the ambient air.

Serum cholinesterase depression is another valid biological indicator of human exposure to organic phosphorus insecticides, which sometimes become general air pollutants when sprayed from aircraft.

Choice of Devices and Instruments

Many devices and instruments are available for the study of air pollution. They range from simple apparatus for identification of a pollutant to elaborate instruments and techniques for quantitative measurement of specific substances. The selection of the method depends on the purpose of the measurements, as discussed previously and, in addition, on a number of practical considerations relating to availability of manpower, money and supporting facilities.

Nature of problem

The specific requirements of the investigation will for the most part dictate the equipment to be used. For example, simple tests using impregnated papers or detector tubes, or in some cases merely an inspection of the area, may suffice to establish that an air pollution problem does exist. The simplest and most economical method adequate for the task should be selected, unless there are specific reasons for doing otherwise. On the other hand, preliminary investigations may reveal the need for additional studies varying in scope from simple short-term surveys to extensive long-period investigations. As the complexity of the investigation increases, the choice of devices and instruments that may be used is limited by a number of general considerations. These are summarized below.

(a) Cost. A limiting factor in most investigations is the money available. It is imperative that the money allocated for measurement devices and instrumentation should balance that allocated for data analysis and interpretation. Too often in the past an unrealistic portion of the budget has been used for the collection of data, with the result that the findings are never satisfactorily interpreted, analysed or reported. In most studies availability of funds will force a compromise between what is desirable and what is possible. However, no compromises should jeopardize the basic purposes of the project.

(b) Availability. Ready availability of appropriate equipment is an important consideration in the selection of apparatus. "Shelf items" are preferable when available, particularly because they are readily serviced and replaced. However, apparatus may in some cases have to be built specially for the job.

(c) Sensitivity and specificity requirements. The need to select a device with sufficient sensitivity and specificity for the needs of the project is self-evident. On the other hand, the selection of equipment that is more sensitive or more accurate than required should be avoided, not only because it costs more but also because it may need more attention and maintenance.

(d) Sampling time requirements. The determination of the sampling time requirements of the project is extremely important and is related to cost. In general, the method of measurement should provide data to suit the sampling time required. Automatic instruments should not be used when simple equipment would suffice. The folly of selecting complex equipment in circumstances where it is not needed lies not only in the production of data which is never used but also in increased costs for its analysis and for calibration, servicing and maintenance of equipment. In many circumstances the selection of a single monitoring station equipped with continuous automatic instruments and with outlying satellite stations with simple devices may produce more information on the distribution and variation of pollutants than a number of automatic stations at the same or greater total cost.

(e) Data output. In certain circumstances it may be desirable to equip automatic instruments with a direct digital read-out or a tape output for automatic data processing. However, a tape output is advisable perhaps only in cases where very short averaging periods of, say, less than 30 minutes, are used. It should be pointed out that a number of steps are required for handling data between a tape output and the computer data analysis programme. These consist of the production of additional tapes based on information in the operator's log for corrections, such as omission of calibration and instrument malfunction periods, instrument drift, etc. The validity of instrument output needs to be checked, preferably by automatic methods. The dependability of automatic instruments and data output systems at present is such that tape output should be added only if really necessary.

(f) Servicing requirements. Instruments should be reliable enough to operate unattended for long periods. This requirement must be balanced against the availability of technical manpower to service and maintain equipment. The extent and frequency of calibration needed may also affect the choice of equipment for a particular project.

(g) Portability, housing and power requirements. In some cases the choice of equipment is dictated by the need to use the same instrument at a number of sites, in which case portability is a dominant requirement. Availability of housing and stable power supply must also be considered.

Instruments for sampling particulate pollution

In addition to the general requirements discussed above, the selection of equipment for sampling and analysis of particulate pollution is influenced by the specific needs of the project. Sampling equipment may be very simple or very complicated, and analytical techniques also vary in complexity. Types of sampling with subsequent analyses may be classified as follows:

a. Suspended particulate matter. Particulate matter small enough to remain suspended in the air is collected by filtration, impaction, electrostatic precipitation or thermal precipitation. Analyses may be made in terms of soiling, total mass, total mass of specific chemical components, total count, count by size fractions or chemical composition by size fractions; other separations may be based on differing physical properties. Sampling equipment ranges in complexity from simple filtration devices to elaborate size classification apparatus. Analytical techniques range from gravimetric analyses for estimating total weight of particulates to micro-methods for identification of constituents in different size classifications. The latter methods are especially important when dealing with particles in the sub-micron size ranges.

b. Settleable dust. Dust which settles out of the air, and which generally comprises particles greater than 10 microns in diameter, is collected in a suitable container over long periods of time, and analyses are made to estimate the total weight or the weight of some specific component.

c. Emissions. Particulates in emissions may be collected from the conduit systems or stack, preferably isokinetically, using techniques that will depend on the size distribution of the particulate, humidity and temperature.

Gases and Vapours

Samples of gases and vapours in the atmosphere or in sources can be collected by employing a number of physical and chemical principles. Analyses can be made by determination of the mass of specific components or of general classes of components. The analytical techniques that can be used range from relatively simple standard chemical methods to advanced techniques such as chromatography of many types, or chromatography can be used in conjunction with other methods such as mass spectrometry and spectrophotometric analyses of various types.

Of special interest for the identification and detection of gases and vapours is the use of simple devices such as indicator or detector tubes and test papers. These are particularly useful for the initial assessment of air pollution problems, although they also may be used in many other types of air pollution investigation.

Indirect methods

Analysis of pollutants or the effects produced by them can be made by using natural or generated electromagnetic radiation or by acoustical techniques. Methods of this type range from simple smoke density evaluations using the Ringelmann chart to advanced techniques now under development which utilize recently discovered physical principles or improved physical techniques. Included in the latter group are passive infra-red radiation for semi-quantitative chemical measurement of plume constituents, infra-red radiation from atomospheric oxygen to make temperature soundings, and laser or radar beam backscatter for inversion height determination, etc. Also included in this class of analyses are those measuring effects, such as corrosion panels, fabric fading and soiling.

Meteorological measurements

Since meteorology has an important effect on air pollution, meteorological equipment may be needed in studies of air pollution.

Ancillary equipment

Various types of miscellaneous equipment or services are required for the conduct of air pollution studies, such as pumps, flow meters, housing for equipment, power supplies and data read-out systems. Mass production and standardization of such devices would be very helpful.

Reporting of results

For the purposes of general assessment, it is desirable to report whether or not a pollutant is present and in what approximate amount in a specified number of samples for specified times, weather conditions and places. Thus the immediate results may be presented in the form of a list of pollutant concentrations present in the samples obtained. If large numbers of samples are analysed, charts, histograms or cumulative frequency distributions are useful.

For identification of sources of pollutants, reports of results should make it simple to determine the gradient in time and space between source and sampling site under specified weather conditions, especially wind direction and speed. As long as the latter requirement is met, averaged data are usually satisfactory. However, if the source strength varies with time, the times of sampling will be of great importance and should be reported.

For assessment of effects on health, a wide variety of reporting methods are used. Since for some pollutants acute effects on health are thought to be produced by short exposures, hourly average data, half-hourly average data, or continuous measurements are desirable. Such measurements yield very large amounts of data for the interpretation of which methods of reporting and data reduction are of great importance. What one usually wishes to know is the number of events, the duration of these events or the proportion of the time in the various sampling plans for which a specified level of pollution has been exceeded. For example: (a) how many times a year (or month) has 0.6 mg/m^3 of SO_2 been exceeded, (b) for how long was this value exceeded once it occurred, and (c) for what percentage of the measuring period was it exceeded?

For some pollutants, such as carbon monoxide, the effect on people is related to an exposure long enough to lead to an accumulation of the material in the body. For this pollutant, four- or eight-hour averages are specially important but, as above, the number and duration of events and the proportion of the sampling period for which certain levels have been exceeded is desirable. Finally, for some pollutants, for example lead, only long-term average exposure is of medical interest. For evaluation of other effects, the reporting should depend on the source and effect.

For assessment of control measures applied to large or complex sources, long-term trends using highly reproducible methods and the reporting of median or average data for several years would be useful or, if the control measure is applied to a source point, reports will be needed comparing measurements before and after control.

For assessment of the relation between weather and pollution, the reporting methods must depend on the specific hypotheses being tested, but mathematical models or selected data will often be desirable, and long-term averages are unsatisfactory.

When continuous recording is used, maximal values are often reported with little attention to the dependence of maxima on the duration of sampling, the intrinsic averaging time of the instrument, or the prevailing weather conditions. Maxima tend to conceal analytical or measurement errors as well, and this is an additional reason why maxima, if reported, should be related to the underlying frequency distribution.

The following reporting methods are to be preferred.

1. For a specified period of sampling or integration, the results can be grouped by frequency of occurrence and a chart drawn up to show this - or, better still, a histogram prepared of the percentage frequency for, or exceeding, a certain concentration.

2. A series of stratified histograms can be drawn for each site, for the whole duration of the study or for selected periods such as a month, a week, all Mondays, or all Tuesdays; or again, in pollution by motor vehicle exhausts, histograms showing data for successive hours of the day, but having selected a certain hour, the scheme of results could cover, say, all Mondays, all Tuesdays, or all the days of the week.

3. All that has just been said concerning histograms applies also to the averages of results, for in addition to the general average of all determinations, there can be monthly, weekly, daily and even hourly averages. The values averaged should be clearly specified.

4. In every case the results should be presented with a view to their being used statistically; graphs or charts are often preferable to tables or figures.

5. Another point of view which should not be neglected is the establishment of a pollution map for a certain region. The principles listed above are again valid as regards the periods of time to be considered. In addition the use of isopleths (lines connecting points of equal pollution) should be attempted.

6. Wherever possible, it is worth while to bring out the correlations in time or space with a pollution factor. Thus curves showing concentration of a given pollutant can be traced on the same time-scale with those showing the emissions of a pollutant source or of wind speed and direction.

Meteorology and Air Pollution Measurements

Air pollution measurements may be made for various reasons. In most cases, however, meteorological information should be utilized in judging the significance of the results of the measurements. The number and type of meteorological measurements will depend on the purpose and complexity of the study and on the availability of data and instruments. Generally available through official governmental weather agencies are data on temperature, humidity, wind speed and direction and precipitation. Data on temperature changes with altitude are often of particular use.

Measurements of the CO_2 content may have significant consequences for the heat balance of the earth's atmosphere. Observations of certain pollutants may help in understanding atmospheric movement. Further, there is evidence that air pollution leads to a decrease in visibility. Although it does not seem probable today that thick fog will occur exclusively because of the presence of pollutants, poor visibility conditions may last longer because of them.

Pollution, especially by particles, can also interfere with solar radiation. Where pollutants are examined for other reasons, e.g., in connection with their influence on health, meteorological factors should be taken into account, as the concentration of pollutants depends on them as well.

as on the properties of the source. Both pollution and meteorological factors may have effects on health.

As long as only a listing of pollutants is aimed at, there may be no need for supplementary meteorological data, but they may be needed in interpreting the degree of contamination observed in the atmosphere.

The most important factors influencing the concentration of pollutants are wind (direction and speed) and atmospheric stability. As a rule, it will not be possible, nor is it always necessary, to measure wind direction and wind speed in every place where pollution measurements are made. The need for such data depends on the purpose for which pollution is being measured.

The meteorological information available can be used with the greatest effectiveness if the time during which the pollutant is sampled is short - not much longer than, say, one or two hours. As a rule, one should proceed cautiously when combining the averages or totals for the concentration of a pollutant determined over a long time, such as a month, with wind data, e.g. with the amount of time during which the wind has a specified direction. It could be that the pollution exposure occurs mostly when the wind has relatively uncommon direction during the observation period.

Atmospheric stability may vary with wind direction and wind speed. The effect of stability, depending on, among other factors, the vertical temperature distribution in the relevant layer, is complex. Stable conditions tend to suppress vertical motions in the atmosphere, but this may have a different effect on pollutants originating from high level sources than on those emitted into the atmosphere at low levels. In the first case (at least as long as there is some wind) the pollutant will not, or will rarely, reach the ground; in the second case it will not be diffused upwards. However, during prolonged atmospheric stagnation, lasting perhaps a week or longer, the daily mixing of pollutants below elevated inversions should not be dismissed from consideration.

It is difficult to obtain reliable information on the stability of the lower 200-300 m of the atmosphere. The best way to obtain this information is with meteorological towers, but these are not available in sufficient numbers. On land, the stability is greatest during the early hours of the morning and least during the afternoon. It must be strongly recommended, therefore, that if observations with a duration of the order of one hour can be made, this should not always be done at the same time of the day as otherwise a bias may be introduced into the analysis. Continuous or repeated measurements are to be preferred to demonstrate the diurnal variation of pollutants. Important meteorological factors are precipitation, which may have a cleaning effect, depending on the size of the droplets as well as on the properties of the pollutant, and solar radiation, which may give rise to chemical reactions. The latter phenomenon is more a chemical than a meteorological problem, but its existence indicates that it is not always possible to compare observations on special pollutants at different latitudes, altitudes and seasons. In such cases it may be of importance to have information also with respect to cloudiness.

The relative humidity may play a rôle as certain pollutants, by virtue of their electrolyte content, can cause deterioration of the visibility, as was mentioned earlier. The presence in the air of aqueous fog droplets facilitates the oxidation of sulfur dioxide to sulfuric acid.

Reliable conclusions from air pollution observations are therefore more likely when air pollution and meteorological measurements are obtained in a co-ordinated manner. This co-ordination should, where possible, begin at the start of the activities, notably when planning the siting of the observation posts in order to make the observations as representative as possible.

The development or evaluation of mathematical models for the diffusion of pollutants from isolated point sources as well as from extended sources like cities must be considered. It might also be useful if information with respect to the influence of topography on the diffusion of pollutants could be studied by means of mathematical models.

Danger to man of certain air pollutants

In addition to the effects of high concentrations of pollutants in stagnant urban air, epidemiological studies indicate that concentrations of pollutants higher than normal but much less than those found in dramatic episodes have perceptible and possibly cumulative effects on susceptible people. Various indices of mortality and morbidity have been used, some of which are described briefly below, but obviously the effects of sub-acute pollution become more readily apparent when many susceptible individuals are studied. Hitherto, studies in the United Kingdom have failed to incriminate specifically and separately either smoke or sulfur dioxide - the pollutants commonly measured as indices of pollution. The implementation of the Clean Air Act in the United Kingdom is happily leading to the reduction of pollution by smoke and further studies of the responses to pollution in which the smoke/sulfur dioxide ratio has altered may enable the separate roles of these two pollutants to be assessed.

Two diseases in the cause of which air pollution is thought to play a part, chronic bronchitis and lung cancer, are demonstrably closely linked to other factors, particularly cigarette smoking. The study of industrial populations - groups of men exposed in their occupation to high concentrations of pollutants suspected of influencing the development of the diseases mentioned above - is of substantial value. The results often discourage the acceptance of simple hypotheses involving irritants and classical carcinogens.

WHO has sponsored several pilot studies of pollution in pairs of European cities and its relation to the prevalence of lung cancer. Results indicate that this expensive and time-consuming technique is of very limited value, chiefly because no assessment of past exposure is possible. If urban environmental surveys are made, they should be related to prospective epidemiological studies.

Epidemiological studies using comparable methods of similarly employed populations in London, rural England, eastern cities in the United States of America, San Francisco and Los Angeles have shown that the persistence of cough and sputum is relatively common in all the cities studied and that cigarette smoking appears to be the major cause of this. The values of pulmonary function tests were nearly identical in the cities on the east and west coasts of the United States of America but pulmonary function tests gave lower results in comparable groups from rural England and were even lower in the London population. The frequency of combinations of persistent cough and sputum with shortness of breath or disabling acute respiratory illness was greatest in London, less common in rural England and least common in cities of the United States of America. These frequencies might possibly be related to air pollution.

Many types of air pollution produce unpleasant odours but quantitative relationships between specific substances or combinations and the responses of various populations need further study.

Irritation of the eyes and respiratory tract is the main symptom caused by photochemical pollution of the Los Angeles type. This has been associated with oxidizing materials in the air. Whether this association will be found in other communities is not certain. This type of pollution appears to aggravate the symptoms of some persons with chronic respiratory conditions, but measurement of this effect has been difficult.

Atmospheric CO levels sufficient to produce two per cent. carboxy-haemoglobin are relatively common in large cities having many automobiles. Two per cent. carboxy-haemoglobin in the blood has been shown to cause interference with psychomotor functions but whether this can influence the ability to control a motor vehicle needs investigation.

Ozone is known to be lethal to animals at concentrations of 6 ml per cubic metre, which is only six times greater than the maximum concentration recorded in Los Angeles. It was recently shown that exposure to 0.6 ml per cubic metre for two hours interfered with the diffusion of gas from the alveoli to the blood in 11 human subjects. How such effects are produced needs to be studied as do the factors, if any, which influence the sensitivity of different groups in the population.

Some pollutants, such as lead, which are stored in the body, may produce toxic or other effects depending on the amount so stored. No harmful effects have been observed due to lead in the ambient air, but further investigation is needed.

Pollution of industrial atmospheres by synthetic organic chemicals and their intermediates is common. The study of the effects produced and the determination of tolerable concentrations is the province of the toxicologist and industrial hygienist. Outside the factory, contamination of the air by synthetic organic chemicals is expected to occur merely as a phase in the purposeful application of these substances to vegetation, soil, and surfaces of buildings and additionally in the storage of foods and in the household. The problems involved in this transient type of pollution are likely to be local in extent and, since the chemical concerned is already identified and its properties known, precautions against its inhalation can be applied accordingly.

Pollution of the communal air by synthetic organic chemicals is probably insignificant. (This hypothetical problem must certainly be regarded in the light of the very real contamination of urban atmosphere by "traditional" and "newer" inorganic substances.) It is doubtful whether the synthetic pesticides, whether formulated as liquids or powders, can easily be redispersed in inhalable form since their formulations and the methods by which they are dispersed are designed to produce maximum retention by the surfaces to which they are directed. Only considerable attrition could produce from these applications particles that might again become airborne in sizes small enough to be inhaled.

TABLE II

AIR POLLUTANTS WITH RECOGNIZED OR POTENTIAL LONG-TERM HEALTH EFFECTS AT USUAL AIR POLLUTION LEVELS

Substances with known health effects acute or chronic	Substances thought to have long-term effects per se (effects are in parentheses)	Potential long-term effects of combinations	Reference
Arsenic	Arsenic (arsenical dermatitis)		
Asbestos	Asbestos (asbestosis, mesothelioma)		
Beryllium	Beryllium (berylliosis)	Be + F (fluorides potentiate pulmonary changes in berylliosis)	Stokinger
Carbon monoxide		Synergistic in pO_2 depression	von Oettinger
Carcinogens		Carcinogens produce tumours in the presence of promotors	
Fluoride		Fluoride (promotes or accelerates lung disease)	Stokinger
Hydrocarbons		HCs + O_3 ⟶ tumorigen + influenza → cancer	Kotin
Hydrogen sulfide (± Mercaptans)		Antagonizes pollutants (not strictly speaking detrimental to health)	
Inorganic particulates	Inorganic particulates (pulmonary sclerosis)		
Lead		With lead from other sources	Kehoe
Nitric oxide		NO ⟶ NO_2	
Nitrogen dioxide	(mild lung tumour accelerator)	NO_2 + micro-organisms (pneumonia)	Ehrlich et al.
		+ HNO_3 (bronchiolitis, fibrosa obliterans)	Gray, Stokinger
		+ tars (smoker's lung cancer)	
Organic particulates (Asthmagenic agents)	Asthmagenic agents (asthma)		Paulus
Ozone	Ozone (chronic lung changes, acclerated ageing)	O_3, lung-tumour accelerator + micro-organisms	Stokinger Coffin
Organic oxidants (Peroxyacylnitrates)			
Sulfur dioxide, trioxide		SO_2, SO_3 + particulates aggravate lung disease	Amdur Lawther

Emissions of synthetic organic chemicals by industry are likely to be very small since they are prime products and not wastes. Some comfort is to be derived from the fact that within the factory, any waste synthetic organic chemicals can be destroyed in the same way as odoriferous gases by feeding the air containing them into the stack, either through the fire bed or at some point before the heat exchanger when the molecule in question may be completely disrupted. The destruction of scrap organic material such as waste plastics ought always to be complete and such material should never be burnt on open dumps.

There is good reason to deduce from investigations on the pollution of air by motor vehicle exhausts that the ultimate fate of organic matter in the air may be complete oxidation. It is undeniable that some chemicals may take part in reactions by which irritant new substances are formed as more or less long-lived intermediates. This type of pollution can hardly be said to be due to synthetic organic chemicals, but exemplifies what might follow the emission into the air of truly synthetic chemicals.

Long-term dangers of air pollution

General air pollutants with demonstrated or potential health effects are given in table II. Air pollutants occurring in local situations (arsenic, beryllium, fluoride) are included because serious long-term health effects have occurred in man and animals living in communities adjacent to industries emitting these substances.

Among the sixteen air pollutants or air pollutant groups, seven are thought to have potential chronic effects (column 2) at levels actually observed. On the other hand (column 3) most of the generally recognized air pollutants may, in appropriate combinations and at certain levels, become a potential threat to health.

These conclusions are derived from toxicologic studies on animals or man, industrial hygiene experiments and epidemiologic studies.

The high respiratory morbidity and mortality rates in urban areas of Europe and North America have led to the idea that inhaling polluted air has, among other things, led to chronic respiratory disease. However, the reported high incidence of chronic bronchitis in smaller towns and villages in Italy and Yugoslavia and the frequency of cor pulmonale in some rural areas in India suggest that factors other than urbanization and smoking may be involved.

The widespread acute and subacute respiratory tract irritation from the soot and SO_2 type of pollution in Europe and from photochemical reaction products in Los Angeles also has led to a supposition that long-term effects on the respiratory system may be occurring. Few studies of the relationship between acute and long-term effects have been made.

In a study of the long-term consequences of an acute exposure to pollutants, which caused an immediate rise in mortality in Donora, it was found that those who only had acute effects in 1948 but no previous respiratory symptoms, showed no increased mortality 10 years later.

Mechanisms of pollutant action and absorption by the respiratory tract, and methods of study

Mechanisms of long-term effects are not well understood. In particular, little is known about the relation of acute reaction patterns of the airway (calibre narrowing, secretion and cough) and long-term effects.

The respiratory tract, within which foreign material once inhaled, may come into intimate contact with the body's circulating blood, has a number of defences.

First there is the complex anatomy of the nasal cavity and upper respiratory tract which causes larger and heavier particles to be deposited by impaction and settlement. Generally, particles of this size are similar to those which are deposited in dust-fall jars used for environmental sampling. Since these particles do not reach the deeper parts of the lung, their health effects are mostly through foreign body reactions of the conjunctiva and their long-term effects are probably relatively unimportant.

The smaller particles (less than about 3μ) usually pass through the upper respiratory tract to reach the deep parts of the lung. There they may be dissolved, if soluble, or ingested by phagocytes if insoluble. They are sometimes deposited peripherally, or filtered out by the lymph nodes. If the particles are one of the forms of quartz or some other minerals, or beryllium, they may ultimately lead to fibrosis or granulomatosis.

Thus it is particle size or more precisely its falling velocity that determines which part of the respiratory tract receives what dose and type of particulate pollution.

By contrast, it is solubility of gases which determines the portion of the respiratory tract which becomes the main target for gaseous pollutants. In high concentrations most of the inhaled sulfur dioxide is absorbed by the mucous membrane of the nose and upper respiratory tract but as the concentration decreases, a smaller fraction of the inhaled dose is absorbed by the airway.

Particulate pollutants (even if chemically inert) and gases such as SO_2 are capable of causing changes in airway calibre measurable by their effects on resistance to airflow. It has been shown in animals that inert particles (NaCl), which alone had little effect, could greatly augment the effect of sulfur dioxide on airway resistance. From this work have grown many additional studies of the effects of particle and gas combinations. Three general principles predominate. First, the particle surface is thought to be a place where gas molecules can react. An example is the oxidation of SO_2 and SO_3 which is facilitated by the action of gas and liquids on a particulate surface. Thus the local concentration of pollutant molecules where a particle impinges on the surface of an airway or alveolus may be much higher than the average predicted from the assumption that the pollutant molecules would be uniformly distributed throughout the inhaled air. The third mechanism is the ability of particles to carry pollutant molecules where they might not otherwise be carried. For example, it has been shown that fine soot particles will bind benzo(a) pyrene so firmly that the substance is carried deeply into the lung and retained there for many days, apparently long enough to cause true squamous cancer of the lung in 70 per cent. of the exposed experimental animals.

The lung may react in various ways. Airway narrowing, fibrotic and granulomatous reactions have been mentioned. Extreme airway calibre changes occur in asthmatics. Secretion of mucus is one mechanism for buffering and dissolving gaseous pollutants and trapping particulate pollutants. Chronic bronchitis is a persisting and exaggerated form of this defence mechanism. The effect on the mucous membrane can lead to its secretory layer being thickened or its secretion being thicker or more viscous. The ciliary beat may be directly affected. This has been demonstrated experimentally in animals after exposure to high concentrations of some of the substances in polluted air. If the layer of mucus is thick and the rate of transport slowed, bacteria and other inhaled substances may remain in the lungs after the initial deposition.

Studies are needed on the effect of different air pollutants on the clearing capacity of the lung as well as on the effects on ciliary activity, thickness and viscosity of the mucus. It is also important to study further the absorption in the upper airways of different gases such as SO_2 and ozone.

Of the substances listed in Table II, sulfur dioxide, sulfuric acid, some of the sulfates, and fluorine are primarily acute, rapidly reacting respiratory tract irritants. To these may be added other pollutants, better known from occupational experience, such as chlorine, formaldehyde and acrolein.

Reactions to ozone, nitrogen dioxide and to some metallic oxides may be acute and severe, but the onset is often delayed for some hours.

Reactions to pollens, cotton and flax dust, and castor bean pomace are thought to involve some immunologic or other time-dependent mechanism.

Beryllium, asbestos and nitrogen dioxide have specific long-term effects, the manifestation of which may not be fully developed for months or years.

Evidence of long-term effects on man

There have been a number of reports of long-term respiratory tract effects with a suspected relationship to air pollution. For a more adequate statement about effects than can now be made, epidemiologic studies of cardio-pulmonary conditions and respiratory function must be supplemented with controlled human and laboratory exposures at realistic levels and with realistic combinations. Such studies in each instance must take into account the role of cigarette smoking, of occupational exposures and of extraneous variables before "cause-effect" relationship of air pollution and chronic respiratory conditions can be accepted.

Chronic non-specific lung disease. Bronchitis morbidity and mortality in Great Britain have been related (in part) to air pollution by a series of careful studies. These have been reviewed in detail in the WHO Public Health Paper No. 15 (Epidemiology of air pollution) and are thus not discussed here. In similar studies in other countries, chronic cough and sputum alone have been shown to have a similar prevalence in many areas with different levels of pollution and these symptoms occur more frequently in cigarette smokers than in non-smokers. However, the frequency of shortness of breath and protracted episodes of respiratory disability was greater in London than in rural England or cities in other parts of the world. Respiratory function tests are similar in their pattern. Similarly convincing evidence has been presented from Japan that chronic respiratory conditions are more frequent in polluted areas.

Emphysema as a reported cause of death in the United States is greater in urban than rural areas. The relationship of emphysema to air pollution is not yet proven as clearly as for chronic bronchitis but possible differences in reporting chronic bronchitis and emphysema may account in part for this.

Health effects of pollution on children. Studies on children using nutritional and respiratory function tests have shown that anaemia, morbidity, altered development and respiratory conditions are associated with air pollution.

Evidence of respiratory and other effects from laboratory studies

Combined exposures

Table II shows very clearly that, at the ordinary levels of air pollutants, or those of the foreseeable future, the potential threat to health on a long-term basis may be expected to arise not from any single air pollutant as much as from air pollutants in combination. Combination may be with other air pollutants or with infectious micro-organisms.

Both animal and epidemiologic studies support this statement on the potentiating effects of air pollutants. It has been shown that a single exposure of mice to trace quantities (a few ppm) of the respiratory irritant ozone increased the death-rate of mice either previously or subsequently infected with *Klebsiella pneumoniae*. Nitrogen dioxide at levels as low as 0.5 ppm similarly synergized the effect of this micro-organism but only after nearly continuous exposure for more than three months. True squamous cancers in the lungs of mice, similar to those found in man, were produced by exposing the animals first to infection with an influenza virus then to large doses of ozonized gasoline. In the animals exposed to ozonized gasoline alone, there were no significant changes; in those with infection alone, approximately eight per cent. showed squamous changes in the bronchi consistent with the healing process after infection, with only an occasional metaplastic change; however, 30 per cent. of the animals exposed to the combination showed squamous carcinoma. Thus the imposition of infection on an air pollution exposure can reveal the effect of air pollution.

Functional studies

Use of the whole body plethysmograph has resulted in many valuable observations on the effects of respiratory irritants on gaseous flow, intra-pleural pressure and tidal volume in both man and animal. Changes in these parameters have been related to known concentrations of SO_2, SO_3, O_3, sulfuric acid vapours, auto exhausts and others, alone and in combination with solid, particulate aerosols. Similarly, the respirometer may be used to measure changes, both in animals and man, in respiratory function (O_2 consumption) after inhalation of air pollutants and thus provide a sensitive measure of physiological alterations in the lung. The rate of diffusion from alveolus to blood of carbon monoxide (DL_{CO}) can be used in man to measure the interference of pollutant exposure with exchange of respiratory gases, and if combined with other measurements, such as vital capacity and forced expiratory volume, to locate the site of action of the air pollutant. The effects on ciliary beat and mucous membranes of the upper respiratory tract can be used to estimate the potential for harm of air pollutants, both particulate and gaseous. Changes in thickness of the secretory layer of the mucous membranes or of viscosity of mucus can also be measured. The effect of air pollutants on lung-clearance capacity and study of the rate of absorption of gases, vapours and particulates in the upper and lower airways offer additional methods of evaluating the effects of air pollutants.

Biochemical studies

Biochemical measures of various kinds provide useful indices of derangements in the normal functioning of the organisms. Although they are often non-specific, they are important sources of information in toxicological studies in the laboratory and could be usefully extended to the evaluation of the effects of exposure of humans to pollutants. Relationship of such changes to long-term effects is not generally known.

Measurement of the rate of release of I^{131} by the thyroid provides an estimate of the toxic stress on the homeostatic mechanism. In animals this has been used to study air pollutants of the respiratory irritant type. The method is capable of measuring other responses of the thyroid to toxic stress, namely the refractive and hyperactive states. Because of its sensitivity it would be useful to make a comparative study of this method with that of behavioural responses. Similarly, changes in adrenal function in response to substances entering the respiratory tract may be measured by determining urinary corticoids.

Quantitative measurement of changes in enzyme activity, the products of enzyme activity (body metabolites) or enzyme cofactors offer basically sound biochemical approaches to the early detection of metabolic alteration resulting from long-term exposures to air pollutants. Biochemical indicators are numerous, and selection should be made to suit the toxicologic needs.

The single biochemical indicator having probably the broadest application to chronic metabolic alteration in animals is lung glutathione (GSH). Significant diminution in lung GSH has been measured in animals following chronic exposure to air pollutants (oils). These changes appeared before evidence of histological change. GSH is a requisite for cellular membrane integrity and for the activity of many important enzymes. Thus those enzymes which depend on SH groups for activity are also good indicators of biochemical changes. The change in serum protein ratios, particularly the albumin to globulin (A/G) ratios determined by paper electrophoresis, is a good, general indicator of metabolic derangement. Ultra-violet absorption spectroscopy is a rapid way to detect and follow changes in the blood and tissues. The more sensitive immunologic techniques for detecting circulating or fixed antibody may be used with certain of the more reactive air pollutants. Changes in this defence mechanism of the body can have important implications in the assessment not only of the degree of toxic stress, but in the elucidation of the mechanism of action of the pollutant. Other immunologic methods have been suggested: counting of plasma cells, and the quantitative determination of change in the capacity of the body under toxic stress to develop antibodies upon immunization. Further study is needed in these areas.

Effects on reproduction and animal genetics

In addition to the "standard operating procedures" of toxicology long used for the detection of chronic changes, such as body-weight, food intake, organ to body-weight ratios, haematological and histological changes, very useful results may be expected from the effects of low-grade exposures on reproduction of small animal species (mouse or rat) through the F_2 generation.

Storage of pollutant

Trends in storage and accumulation of inorganic and organic pollutants and their metabolites may be determined by spectrochemical or chemical methods in body tissues and fluids. Information already exists on the normal accumulation of metals in man in some countries that can serve as a baseline from which to judge change in pollutant storage and accumulation. Spectrochemical, but preferably, chemical analysis of the lung and liver for metal shifts of essential trace elements such as copper, molybdenum and zinc reveals remarkable changes in tissue content following long-term exposure to air pollutants in animals.

Production of tumours

A highly sensitive procedure is the use of a lung tumour susceptible strain (e.g. CAF_1/Jax) of mice of known high tumour incidence. Exposure of this, or similar, strain of mouse to air pollutants and the periodical examination of the lungs for tumours, and comparison with suitable controls, may be used to measure the lung-tumour accelerating (or inhibiting) potential of the air pollution.

Control and prevention of air pollution

The control of air pollution is ultimately an engineering problem. In principle it should be possible to reduce the environmental air pollution below the levels recommended by air-quality guides by applying one or more of the following procedures: (a) containment, i.e. prevention of escape of toxic substances into the ambient air; (b) replacement of certain technological processes or fuels by new ones which produce less air pollution; or, (c) reduction of concentration of toxic substances in air by dilution. These three engineering methods may be supplemented by restriction in the use of substances that may become air pollutants, e.g. pesticides.

Containment can be achieved by a variety of engineering methods such as enclosure, ventilation and air cleaning, which are highly effective, particularly in nuclear sanitary engineering. It should, however, be pointed out that the improvement of containment methods has been accompanied by a considerable rise in the operating cost and that the economic factor often seriously hampers their application. It should also be noticed that containment methods, although very efficacious, are never completely effective.

The second principle of engineering control, that of replacing a technological process producing air pollution by a new one free of air-polluting products, has been considerably less successful in practice. The reason is obvious. The new substitute process has to be technologically equivalent to the old one in all essentials such as the quality of the final product, the availability of raw materials, etc., and it has also to be satisfactory as regards cost of production. All these requirements are difficult to meet and call for costly long-term industrial research, accompanied by similarly expensive and lengthy toxicological research. But substitution may in certain cases be the only solution to a specific air pollution control problem. The restriction of the use of potentially harmful new synthetic chemicals depends on the availability of adequate substitute substances or processes.

The third principle dilution should be used only if the first two methods are not applicable or are unsatisfactory for either technological or economic reasons.

II Water Pollution

Trends and health significance of increasing pollution

The total natural freshwater resources of the world and of each general area of the world are relatively fixed by hydrologic forces. The use of these resources, however, is increasing rapidly as a result of continued population growth and industrial expansion. Along many of the major rivers in highly developed countries, fresh water is used over and over again as it flows from highlands to the sea. Each use changes the quality of the water, generally to the disadvantage of subsequent users and of aquatic life. There is a limit to the waste products that a stream or lake can assimilate without serious effects on man's physical, mental and social well-being. This limit has been reached or exceeded in many instances.

In almost all of the developed countries, there is growing concern over the ever-increasing introduction into the water of chemicals and radioactive materials with carcinogenic, toxic and physiological effects on man.

In spite of the increasing complexity of the microchemical pollution of water, the biological aspect is still important. Water-borne outbreaks of typhoid fever still occur whenever favourable epidemiological factors coincide with inadequately treated water supplies. High carrier rates and high resistance to chlorination by the enteroviruses are two factors in the prominence of such virus diseases at a time when the enteric bacterial diseases are declining. The carrier rates of enteroviruses in children under 15 years average 10 per cent, in the United States of America and can be expected to be much higher in less developed countries. Little is known of the carrier rates of infective hepatitis, but they may be high, where environmental sanitation is poor. The relatively high incidence of this disease, the increasing numbers of small water-borne outbreaks, and the occurrence of epidemics associated with shellfish harvested from polluted waters support this belief.

Free-living nematodes, protozoa, and rotifers are the major groups in the zoological phase of aerobic sewage treatment. They are present in large numbers in the effluent. When an effluent enters a natural watercourse, such as a stream, it receives the viruses, bacteria, and zoomicrobes carried in the effluent. In the treatment plant, the zoomicrobes feed mostly on bacteria growing on organic particulate matter. Nematodes recovered from effluents from trickling filters and primary settling plants have been found to contain in their gut small numbers of E. coli and streptococci. Pathogens can survive one to two days inside the nematodes. In times of large epidemics, many persons are discharging pathogens into the sewage and these nematodes may then serve as carriers.

Other zoomicrobes, especially swimming ciliates, feed actively on suspended bacteria, including Salmonella and Shigella organisms, but they are apparently incapable of ingesting viruses, which are too small to be entrained by the cilia. The ingested bacteria are so rapidly digested that the carrier problem with these protozoa, if it exists, is very remote indeed.

Most biological pollution can be effectively eliminated by most conventional water purification systems, but in many developing countries the water to which people have access is not necessarily safe. According to statistics compiled by WHO, only 20 per cent. of the world's population have access to piped water supplies and if highly developed countries are excluded, only five per cent. of the remaining population enjoy this facility.

In addition to the chemical and biological degradation of surface waters and ground waters, serious consideration must be given also to physical pollutants, among which heat and radioactivity are the most important.

A high temperature of surface waters is accompanied by de-aeration and a resultant loss of dissolved oxygen, with marked effects on the fauna and flora of the water. Not only is the supply of oxygen reduced but its rate of use for metabolic processes is increased; hence heat contributes doubly to the de-oxygenation of surface waters. Thermal pollution is also serious in that it interferes with the subsequent uses of water by industries and municipalities.

It is not only the pollution of fresh water that must be considered. For example, migratory fish such as salmon pass from the sea, through estuaries, to freshwater streams. In many industrial countries there are large towns and factories on the banks of estuaries, which in consequence are often much more highly polluted than the freshwater streams emptying into them. This is certainly the case in the United Kingdom, where important salmon fisheries have been destroyed through estuaries becoming impassable to adult and immature salmon, even though the rivers discharging into these estuaries are themselves comparatively unpolluted.

Chemical contamination of water

Sources of pollutants

The chemical contaminants that enter the surface and ground-waters of the earth do so in three principal vehicles: (1) wastes and waste waters from sewered and unsewered communities; (2) wastes and waste waters from industry not connected to public sewerage systems; and (3) surface run-off and underground seepage from rainfall collected by the drainage systems of urban and rural areas.

Within sewered communities, households and institutions are major contributors of spent synthetic detergents, industries less so. Conversely, industries are the principal contributors of other synthetic organic substances either as waste products of their own manufacture or as spent liquors from other manufacturing processes. Discharges into water vary in kind and concentration with the nature of the industry and the conditions of manufacture. The concentration and, in the case of non-persistent substances, the nature and concentration of their intermediate and end-products of decomposition are normally altered by sewage treatment before effluents reach water-courses. The kind and intensity of cleansing operations is, therefore, important in chemical water management.

In unsewered communities discharging wastes to the soil or possibly to the land and thence to watercourses, undergound waters and surface supplies may also be contaminated. Where water is drawn from the ground and the resulting waste water is returned to it through nearby leaching devices, spent chemicals may remain substantially unchanged in constitution and concentration.

Industries requiring large quantities of process or cooling water are often situated on important water-ways. With direct communication between intake and discharge through the works, the opportunity for the release of unaltered chemical wastes by intent or accident is increased.

Run-off and seepage from rainfall in urban areas appear to be of importance in modern cities chiefly when rates of precipitation and their duration are high enough to spill appreciable quantities of sewage and scourings from combined systems of sewerage into waters that are otherwise well protected against pollution during dry weather or when rainfall is light. Shock loads of waste chemicals may then be poured into receiving waters and travel downstream in "piston flow" or move about in lakes, ponds and reservoirs as slugs high in concentration of pollutants before their ultimate dilution by dispersal.

About the chemical pollution of so-called natural run-off and seepage, we know little, but we must assume that these intermittent flows contain suspensions and leachings of substances added to cultivated lands, fields or forests.

Nature and concentration of pollutants

Because the chance as well as purposeful water-carriage of waste substances is part of our present, strongly hydrologic and hydraulic civilization, the waters that must be drawn upon to slake the thirst of man and beast conceivably contain, at one time or another, and in one place or another, every kind of chemical that man is winning from nature or synthesizing for his use. Hence, the degree of pollution with chemicals and the size of the population at risk determine the danger being created. Composition of the population and amenability of chemical pollutants to removal, modification, or destruction by common or specialized treatment processes are significant but lesser determinants.

Synthetic detergents. That synthetic organic chemicals do reach both surface and underground waters and may do so in appreciable concentration has been amply demonstrated by unsightly foams covering rivers, ponds and lakes and issuing from springs and wells. Because the persistent anionic detergents, which are almost wholly responsible for these visible signs of water pollution, are non-toxic in a practical sense - although information on the effects of long-term ingestion on man are not yet fully documented - administrative action against their use is based primarily on aesthetic grounds. In water-supply, however, palatability and attractiveness, although secondary to toxicity, are not factors that can be lightly brushed aside. Of further interest is the inclusion in detergent formulations of so-called builders which contain among other things, condensed phosphates as sequestering agents. These, too, are non-toxic, yet they are key elements in the eutrophication of lakes and other deep bodies of water. By providing essential nutrients to algae, diatoms, and other plankton organisms, phosphates increase the number and intensity of blooms or sudden growths of these organisms in large numbers. Unsightly and odoriferous scums are formed and interfere with the enjoyment of bathing waters. Moreover, they make the production of adequate amounts of palatable drinking-water difficult.

Identification of synthetic organic chemicals in water. With some exceptions, the toxic hazards of modern synthetic chemicals that find their way into drinking-water are not known with certainty; nor can we anticipate rapid acquisition of necessary knowledge until we are able to identify the nature and concentration of the pollutants that may be of concern.

Using the carbon-chloroform extract technique which involves passage of almost 20 000 litres of river water through a carbon filter followed by extraction of the adsorbed materials by chloroform, it has been possible to recognize a gradation of river waters in the United States of America from relatively clean waters to waters seriously polluted by industrial wastes. Exemplifying light domestic pollution was the Columbia River at Bonneville Dam, Oregon, with 24 parts of CCE (carbon-chloroform extract) per 1000 million; exemplifying heavy industrial pollution the Kanawha River at Winfield, West Virginia, with 457 parts of CCE per 1000 million. Moreover, the presence of DDT, aldrin, orthochloronitrobenzene, tetralin, naphthalene, chloroethyl, ether, acetophenone, diphenyl ether, pyridine, and other nitrogen bases; phenols of various kinds, nitriles, acidic materials; miscellaneous hydrocarbons, including substituted benzene compounds, kerosene, synthetic detergents, aldehydes, ketones and alcohols could be identified in the CCE. Some of these substances are known to be toxic. Many other compounds, undoubtedly present, remained unidentified. The application of chromatographic and spectrophotometric methods have since made analysis easier. It has been possible to identify in river water representative chlorinated insecticides in concentrations of less than 10 parts per 1000 million by carbon filter sampling, adsorption chromatography, and infra-red spectrophotometry.

Accumulation of contaminants. Of much significance is the fact that present methods of waste-water treatment leave many dissolved chemicals unchanged. Consequently, the concentration of contaminants increases as water is re-used. Downstream communities are then exposed to increasing concentrations and varieties of chemical pollutants. In comparison with the figures for the Columbia and Kanawha Rivers, for example, the heavily polluted Detroit River near Wyandotte, Michigan, and the Merrimack River at Lawrence, Massachusetts, yielded respectively 465 and 743 parts per 1000 million of CCE. At Chanute, Kansas, wastewater recirculated through a reservoir on the essentially dry Kaw River, contained 992 parts per 1000 million of CCE.

Pesticides in water. DDT has been found in a number of large rivers of the United States of America in concentrations of 1 to 20 parts per 1000 million. Pesticides applied to vegetation or soil for the control of agricultural pests are incorporated in part into plants or remain on them as residues, are volatilized in part or fixed in the soil, degraded in part or left unchanged, and ultimately leached in part from the soil by rainfall or irrigation water to appear as run-off or percolation. Transport and degradation vary with the particular chemical and its contacts. Much has been done to discover the fate of pesticides for the benefit of the user of the product; little for the benefit of water quality management. What the significance is of a potential threat of pesticidal chemicals to drinking-water supplies remains to be shown by further investigations and research. Nevertheless, it is clear that the wide use of chemical pesticides has created a new water pollution problem which cannot be solved in the same way as problems connected with the discharge of sewage and industrial waste have been solved in the past. The economic usefulness of insecticides is so great that increasing quantities of these synthetic chemicals must be expected to reach water supplies. Accordingly we should be prepared to remove them when they appear in significant concentrations. The current trend, however, is to avoid difficulties by developing less stable pesticides for use in agriculture.

Carcinogens. Petroleum products and refinery wastes are generally listed among possibly mutagenic and carcinogenic substances. That there are surface waters into which industrial plants discharge wastes containing substances of this nature has already been suggested. The recovery of various polycyclic aromatic hydrocarbons from sewage sludge has been reported among them the known carcinogens, 3,4-benzpyrene and 1,2-benzanthracene. Effluents from gas-works, run-off from macadam roads, and atmospheric soot washed from the air by rain are suspected of introducing these chemicals into sewage. Carcinogenic aromatic amino compounds, such as betanaphthylamine and benzidine, originate in dye and rubber works and may be released to public sewers together with nitro-analogues used in the production of amino compounds, such as aminoazo-dyes, amino stilbenes, and tri- and di-phenylmethane dyes. Pharmaceutical factories, textile dyeing plants, plastic-production operations, and related industries are other sources of these organic substances. Some of the intermediates such as orthochloronitrobenzene, have been found in the Mississippi River in appreciable quantities. They may be quite stable. For example, chloronitrobenzene discharged to the Mississippi at St. Louis, Missouri, was still demonstrable in water drawn at New Orleans, Louisiana, hundreds of miles or many days' flow away.

It must be concluded, therefore, that there is reason to suspect the presence of possibly dangerous compounds in polluted waters and that prolonged or life-time consumption of water from polluted sources will increase the normal burden of carcinogens from all sources. In the absence of reliable methods of analysis for dangerous compounds, we must turn to longitudinal epidemiological studies of populations at risk to provide needed - in this case, unfortunately, only circumstantial - evidence. Ultimate decisions on the conditions and degree of exposure of populations must rest on information derived from careful studies of the fate of pertinent chemical pollutants.

Toxicological standards

In reference to the newer organic synthetic chemicals, there is an urgent need for close study of man himself in relation to his ingestion of relatively small amounts of possibly dangerous substances over a prolonged period of time. Information based upon bio-assay through various aquatic organisms, as presently conducted, is not directly applicable to man. Fish, for example, can absorb and release toxicants without necessarily metabolizing them. Accidents, so useful in identifying levels of acute toxicity in industry, would not necessarily tell much about chronic poisoning. Current methods of testing for chronic toxicity on experimental animals are normally conducted on groups of animals which are relatively small when compared with the size of human populations likely to be exposed. Therefore, effects with a low incidence would go undetected. Moreover, studies on animals are not expected fully to reflect the effects of toxic substances on man. Synergism and additive effects of toxicants are possible and should be studied.

In the circumstances, it may be possible to adduce information from experience in industrial hygiene, especially when the toxicological data on which industrial standards have been based include animal feeding experiments as well as observations of the reaction of substantial populations at risk.

The present feeling of many public health authorities is that no permissible concentration should be set at this time for known carcinogens among the new chemicals.

Aquatic food-stuffs

Fish and shell fish constitute almost the sole human food that comes from natural waters. The vertebrates are sensitive to a wide variety of organic chemicals. Consequently, suitable species are used in bio-assays to detect chemical pollution. Since the most probable effect of chemical pollution of water is the death of the fish tested, the danger is easily recognized. However, it is possible that fish and other aquatic creatures used as human food may prove unsusceptible to substances which are very poisonous to man. For example, an "epidemic" of neurological disease was attributed to the eating of fish that had accumulated alkyl mercury compounds from a factory effluent discharging to fishing grounds in the sea. This potential danger underlines the need for care in keeping dangerous factory effluents away from sources of human food.

Current problems

Synthetic detergents and their residues

The history of pollution by detergents may serve as an example of the consequences of introducing a new type of microchemical contaminant into the aquatic environment, and of the measures which have been taken to alleviate the nuisance caused thereby. The household detergent mixtures which began to be marketed on a large scale some fifteen years ago, contained as their essential component an alkyl benzene sulfonate (a molecule comprising a benzene mucleus to which was attached a sodium sulfonate group and an alkyl chain containing usually eight or more carbon atoms). When the materials were first used, this alkyl chain was branched, a circumstance later found to be of particular importance though the significance of it was not realized when the materials were first put on the market.

It soon became apparent that this type of surface-active material was particularly resistant to decomposition by bacterial action. In this respect it was very different from the soaps which it replaced, since these undergo rapid decomposition and do not give rise to any particular difficulty in waters to which they are eventually discharged.

Because of their resistance to bacterial attack, the early forms of alkyl benzene sulfonate were only partially decomposed during treatment of sewage, and approximately half the quantity originally present was subsequently discharged with the sewage effluent. A characteristic property of these substances is that they reduce the rate at which oxygen is transferred from the gas phase to solution in a liquid. Since the purification of sewage by bacterial action is essentially an aerobic process, efficient solution of oxygen is very important, and expensive methods of aeration are necessary to achieve it to the desired extent. Thus, the presence of detergent residues, by interfering with this process, greatly increased the cost of sewage treatment. If additional aeration plant was not provided, there was a serious deterioration in the quality of the treated effluent.

Passing over this, however, the residues discharged to surface waters also caused a serious deterioration in their quality. The unsightly foaming which occurred in many rivers, particularly below turbulent reaches, is well known. Another less obvious, but equally important effect, was that the rate of solution of oxygen from the air by the surface water was reduced, so slowing down the processes of self-purification below points of discharge of sewage effluents. Furthermore, it has been held by some workers that detergent residues have an adverse effect on aquatic plants and animals. This perhaps applies where the residues are present in unusually high concentrations.

After much technical discussion on possible methods of dealing with these difficulties, it has now been widely concluded that the most (if not indeed the only) practicable step is to develop substitutes for the original form of surface-active material, more susceptible to bacterial attack. This has led to a very great amount of research by the manufacturers concerned. Many hundreds of experimental materials have been tested, and the goal of producing substantially or wholly degradable substances on a large scale may now be said to be within sight.* One clue to the direction to be taken was that it was found that if the alkyl side chain of carbon atoms was straight instead of branched, resistance to bacterial decomposition was greatly reduced. This brief history is presented as a background to the more recent problem posed by the increasing use of other synthetic organic substances, notably pesticides.

Other synthetic organic substances

The presence of persistent synthetic organic substances in sewage could only constitute a health hazard in cases where the effluents reach sources from which water is later taken for domestic or municipal supplies. It is of course assumed that the water from such polluted sources would be adequately treated and disinfected before distribution. Where this has been done, the evidence available is that the treated water has no adverse effect on human health. For example in the United Kingdom, where part of London's supply is taken from rivers which have received sewage effluents, and part from deep wells, the returns of health statistics submitted by the Registrar General have not so far revealed significant differences between health indices of the communities served by the two sources. Presumably if the concentration of these organic biologically resistant substances is increasing in waters used for public supply, it is to the extent that the concentration of sewage effluent in the waters is itself increasing.

There has, however, been a more rapid increase (at least in industrialized countries) in the quantities of persistent organic materials discharged into water systems from industrial processes of all kinds, for example those from the oil and chemical industries. Some of these substances have been identified and determined using refined modern techniques. The presence of at least some of these contaminants in water used as a source of domestic supply is certainly

* A high proportion of the synthetic detergents in use in 1966 are largely degradable. Whether these substances are more or less toxic than the older synthetic detergents is not yet known. One study suggests that they - or their degradation products - are more toxic to fish than the older synthetic detergents.

undesirable. In many cases, however, a technical remedy is available, i.e. the application of existing treatment methods or the development of new ones to remove the compounds from the industrial effluents concerned before their discharge.

Turning to the synthetic organic pesticides, much of the research on their environmental side-effects has been undertaken in the United States of America. Elsewhere, in the United Kingdom for example, the application of pesticides and ensuing wildlife mortalities are clearly at a much lower level. Nevertheless, the United Kingdom too can point to recent noticeable bird losses. Much wildlife loss attributable to pesticides does not of course concern aquatic habitats. However, with specific respect to the latter, the American data still furnish reliable evidence that various organisms have suffered harm on a significant scale. It is mainly on this evidence that we must at present depend in predicting what the consequences may be in other countries where increasing amounts of synthetic organic pesticides are being used.

In the first place, pesticide residues in concentrations of 0.1 to 5 parts per thousand million have been found in the major river systems of the United States of America. Such concentrations are small, but their effects are far-reaching. Thus the direct toxicity of some pesticides to fish is extremely high, as is shown by the fact that within four days, half of a test sample of trout had died as a result of exposure to endrin in a concentration of only 0.5 pp 10^9.

Secondly, it is well established that pesticides present in small amounts in water can be concentrated many-fold by aquatic organisms, including algae, and that the degree of concentration may thereby increase from link to link in the food chain. Thus, although fish may not themselves be killed at lower levels of such microchemical pollution, their bodies may nevertheless contain sufficient pesticide residues for the ingestion of numbers of them to harm or cause the death of birds which feed on them. In this connection, it is very relevant that in the United Kingdom (where despite regular observation and investigation no fish kills in surface waters have so far been attributable to pesticides, except on a very few occasions through abnormal causes such as accidental discharges) the first indication that a serious state of affairs might be developing was the finding of high concentrations of residues in fish-eating birds.

In the United States of America there is much circumstantial evidence for the claim that in some districts fisheries are being seriously threatened by pesticide hazards. For example, in New York State reproduction of trout is known to have been reduced significantly at the time when the egg-yolk (in which DDT had accumulated) was being absorbed by the developing fry. In other areas there has been massive mortality of fish immediately after pesticides have been applied by spraying from aircraft. Sometimes mortalities have occurred after the first rain following the spraying, and experiments in Georgia demonstrated the toxicity to fish of run-off water from a sprayed area. Long-continued assessments of the results of aerial forest spraying for spruce budworm control in the drainninage basins of many leading salmon rivers in New Brunswick, Canada, have furnished much specific information on the consequences to aquatic organisms. In most operational sprayings between 1954 and 1960, DDT was applied at 1/2 lb/acre. After such treatments, the aquatic insect fauna typically declined sharply, emergence being nullified for up to six weeks. It was found that the larger bottom-dwelling species, which are the preferred food of larger parr,[1] required long periods to become re-established qualitatively - stone-flies needed at least two years, mayflies three years, and caddis-flies, four years. Not until after four to five years with no further spraying did the species composition of aquatic insects return to normal. As regards direct harm to fish, young salmon of all size groups were found in greatly reduced numbers after spraying, underyearlings being only 2 to 10 per cent. as abundant as before. Small parr were 30 per cent. and large parr 50 per cent. as abundant as in unsprayed situations, and the growth rates of the survivors were affected adversely because of the disturbance of their food supply already mentioned. Since 1960 DDT has been applied to a considerable extent, at 1/4 lb/acre. Single applications at this dosage have resulted in appreciably lower fish mortalities, and recent trials with the systemic insecticide, Phosphamidon, at 1/2 lb/acre, have indicated that it is a promising substitute for DDT, causing insignificant harm to fish populations and giving no demonstrable effects on aquatic insects in three weeks following spraying.

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[1] Most New Brunswick young salmon spend three years in rivers migrating to sea; they can be placed in three size groups roughly comparable to each year of life, namely underyearlings, small parr and large parr.

Again, the employment of extremely sensitive methods of chemical analysis to investigate recent massive fish mortalities in the lower Mississippi river, has demonstrated that the concentration of endrin in the blood of these fish was sufficiently high to have caused their death. More surprisingly, it is now being reported that marine fish (even in comparatively open ocean waters) are proving to exhibit measurable concentrations of pesticide residues. In fact, some of the most striking evidence on the accumulation of residues of pesticides has come from the examination of estuarine and marine fish and the sea birds feeding upon them. An early and very well known example of the extent to which such residues can accumulate in fish-eating birds, concerns Clear Lake, California, United States of America. In 1954 and again in 1957 this lake was treated with DDT at a concentration of 2 pp 10^8 for the control of the non-biting gnat, Chaoborus astictopus; after the second application, breakdown products of the compound were detected at a level of 1600 pp 10^6 in the fatty tissues of western grebes found dead there. Very recently, figures have been obtained for the concentrations of DDE and dieldrin in the eggs of British fish-eating birds feeding from waters to which synthetic organic compounds had never been directly applied for pest control. As examples of the levels demonstrated, from 8 to 28 pp 10^6 of DDE and dieldrin together were found in the eggs of herons (Ardea cinerea) and from 1.6 to 3.2 in those of terns (Sterna spp.).

Long-term dangers of water pollution

The establishment of drinking-water standards differs in one notable way from air standards for occupational exposure; the number of substances in water whose limits are regulated is kept to a minimum because the promulgation of a standard is tantamount to the requirement of periodic analytical checks to assure compliance with the standard, which is impracticable when hundreds of substances are included. Two regulatory devices are, however, used in water pollution which make it unnecessary to test for a large number of individual substances:

1. Use of limiting concentrations of indicator substances, e.g. alkyl benzene sulfonate, as an index of synthetic detergent pollutants, water re-use and general level of contamination.

2. Use of group analysis, e.g. total dissolved solids (TDS), and the substances which can be extracted by chloroform from carbon filters (CCE) as indices respectively of inorganic and organic chemical pollution. Thus a single analysis may provide an index of either total dissolved mineral or total organic pollution present.

In warm climates a much greater daily drinking-water intake can be expected than in temperate countries, and up to fivefold greater amounts of water-borne pollutants may be ingested. The populations of the former, therefore, might ingest as much as five times more of water-borne pollutants than the latter, with equal concentrations of pollutants in drinking-water. Much of the work on existing standards is based on intake in temperate climates, and criteria for their application to warmer areas should be developed and applied. Important mechanisms that produce synergism via the respiratory tract are not operative in the gastro-intestinal tract; an example is the adsorption of gases and vapours on particulates. The apparently potentiating effect of micro-organisms and pollutant combinations in the lung does not appear to be of importance in the gastro-intestinal tract. As in the lung, however, the potentiated action of carcinogens by promoters and accelerators still obtains.

There is undoubtedly concern by some laymen as well as by scientists that man is ingesting pollutants of food and water which may have now or in the future adverse effects on human health. They point out that industry is producing many new substances which find their way, either intentionally or unintentionally, into food and water. They fear that these substances have been introduced without sufficient evaluation of their possible health hazards.

Food may be, quantitatively, a more important source of ingested pollutants than water. The following discussion will be focused on pollutants of water, but in any consideration of health effects of ingested pollutants the contribution of food cannot be excluded.

Water, as it occurs in nature, is always a dilute aqueous solution of organic and inorganic substances. Potable water is generally considered to be a colourless, clear solution without unpleasant odour and taste which contains no more than 1500 mg/l of total solids and no more than specified amounts of

TABLE III

SELECTED WATER POLLUTANTS WITH POTENTIAL LONG-TERM EFFECTS
(incomplete list)

Elements or substances	Indicator substances
Arsenic, As, particularly AsO_3	Alkyl benzene sulfonates, ABS (index of pollution by all synthetic detergents)
Barium, Ba	
Cadmium, Cd	Carbon chloroform extract, CCE (includes most organic compounds including organic carcinogens and pesticides)
Chlorine, Cl_2 (with reaction products from organic pollutants may have toxic potential)	
Chromium, CrO_3	Phenol (includes phenols, cresols and homologues)
Fluoride, F	Total dissolved solids, TDS (includes minerals contributing to "hardness")
Lead, Pb	Gross beta radiation (as an index of mixed radioisotopes in the absence of $Strontium^{90}$ and alpha-emitters)
Mercury, Hg	
Nitrate, NO_3	
Selenium, SeO_2, SeO_3	
Vanadium, V	

certain contaminants (WHO International Standards for Drinking-Water - 1963). In addition to standards of chemical purity, potable water must also conform to certain standards of microbiological purity.

Not every possible pollutant of water, however, is identified in the International Standards and there are many pollutants for which safe limits have not been specified. Hence water conforming to the International Standards may, in fact, be unsafe and may produce adverse long-term effects on health. There is no scientific evidence, however, that such adverse effects on health have been produced as yet. There remains only the fear that they might occur in the future.

The number of inorganic water pollutants is smaller than the number of organic pollutants. The most important inorganic pollutants have been identified in the International Standards for Drinking-Water and safe limits for them have been recommended.

Metals in water

Mineral pollutants other than those listed in the International Standards for Drinking-Water may occur from time to time in specific places. In connection with industrial exposures, there are about 50 metals which are of special interest. Metals of the type represented by lead and mercury continue to be the most important, but many other metals such as arsenic, beryllium, cadmium, manganese, chromium, nickel and vanadium have become of increasing toxicological importance. Table III gives a list of some selected water pollutants with potential long-term effects.

The general population is less concerned about industrial exposure than about the exposure which takes place *via* food, water and polluted urban air. This exposure is not generally large enough to cause clearly demonstrable toxic conditions. It does, however, result in deposits of a number of substances in the body. It is possible to demonstrate the presence not only of substances vital to the body such as copper, cobalt, molybdenum, manganese and zinc, but also of potentially toxic substances such as cadmium, chromium, vanadium, nickel and lead. There is also organ specificity for certain substances while other substances are more evenly distributed in the body. Certain substances have a marked variation in relation to age. The amount of chromium decreases with increasing age, while that of aluminium in the lungs and cadmium in the liver and kidneys increases with age.

Specific water pollution by mercury has occurred in the coastal waters of Japan as a result of industrial waste disposal. This pollution indirectly caused human disease and deaths which were the result of eating fish taken from the waters. The fish had absorbed sufficient mercury from the water to become toxic foodstuffs. Whether the water itself would have been toxic is not known since it was not used for drinking. This emphasizes that pollutants of water may reach man as food originating in the polluted water.

In recent years the possibility has been suggested that certain metals in concentrations normally present in the body might contribute to the development of chronic diseases. The hypothesis is that certain essential metals form complexes, for example, iron and cobalt in the porphyrin chelates, heme and vitamin B_{12}. It is feasible that other metals might compete for a ligand with an essential metal on a metallo-enzyme. The administration of one metal might thus create an effective deficiency of another. Cadmium and mercury, stored for example in kidneys and testes, might thus displace zinc owing to their chelation with ligands which normally chelate with zinc. This is only an example, but other mechanisms may, of course, be considered. The possible toxicity of trace metals has been raised in connection with the endemic nephropathy in Bulgaria, Yugoslavia and Romania.

Epidemiological studies carried out in Japan, the United States, England and Sweden have shown higher mortality rates from cerebrovascular and cardiovascular diseases in people living in areas with soft water than in areas with hard water. The amount of calcium in the drinking-water is only a few per cent. of what is ingested in food. Calcium in water may, perhaps, be correlated with other substances, e.g. trace elements or organic components. Epidemiologic studies need to be broadened and the several substances (for example magnesium) which might provide further insight into this problem need to be tested in the laboratory.

Pesticides in water

Another class of water pollutants of great interest is the pesticides. These are a group of pollutants which are a new hazard, not only to the people who are occupationally exposed, but also possibly to the general population. Pesticides can occur in water, soil, food (including milk, fruits, and fish living in polluted waters), and in air, especially in rural areas and where they are widely used for agricultural purposes.

The pesticides in greatest use today are organic compounds of some complexity, although pesticides based on arsenic, lead and mercury are still used. Pesticides reach water supplies directly as the result of the intentional application for the control of pests in the water, or unintentionally from run-off from agricultural areas, from careless aircraft spray application to adjacent fields, from industrial waste disposal and by ground-water and subterranean water transfer.

Much is known about the toxic effects of the organic pesticides when ingested. The acute and subacute toxic effects are known for a number of animals and, in many instances, for man. If the pesticide is to be used on raw agricultural products, the chronic toxic effects will have been evaluated in rats and perhaps in dogs based on the addition of the pesticide to the diet for periods of up to two years, or on the demonstration that the pesticide is metabolised to one or more other products whose chronic toxicity is known. This information, which would usually include a level of dietary intake which produces no detectable adverse health effects over the feeding period, is usually a preliminary to the establishment of a maximum permissible residue on raw agricultural products.

While there is some experience with acute toxic effects of pesticides on man, relatively few examples of chronic toxic effects on man have been recorded.

The toxicity of the more important pesticides is reviewed in the FAO/ WHO publication Evaluation of the toxicity of pesticide residues in food.

The ill-effects of ingesting in water very small amounts of pesticides, if they occur, have yet to be demonstrated. In the absence of direct human experience, reliance must be placed on experiments on laboratory animals.

The nature of these experiments will vary according to the practice of different nations, but the basic principles of such work are set forth in WHO Technical Report Series No. 144 (Procedures for the testing of intentional food additives to establish their safety for use). In general, such investigations include the feeding of the pesticide to rats, and in some countries to dogs also, as a part of their diet for two years. Several dietary levels of the pesticide are fed and the lowest dose level should be so selected that the animals receiving it throughout the two-year period will be expected to show no discernible ill-effects. Two years cover the most of the life-span of the rat.

The results of the many experiments on animals which have been carried out lead to the following conclusions:

1. The chronic toxic effects of the pesticide diminish with decreasing dose.

2. A low, but still finite, dose level can be found which in the lifetime of the rat, and for two years of the life of the dog, produces no detectable toxic effects as measured by growth, behaviour, life-span, reproduction, biochemical and haematological values, and by gross and microscopic pathological examination.

Such low levels are called "no-effect" levels and in the United States a residue tolerance for a pesticide on specified raw agricultural products must be derived from a demonstrated no-effect level by the application of a factor of safety, usually of the order of 100, designed to take account of the fact that man may be more sensitive to the pesticide than the laboratory animals used.

It may be objected that conclusions based on animal experiments are not relevant to man. Drug effects in man, however, do follow the general rules deduced from animal experiments in that effects diminish with decreasing dose and disappear at some small but definite dose. Also the method used by the United States Food and Drug Administration to establish safe residue levels of pesticides in food has been based on animal experiments and there is no sound evidence as yet that the method has led to any serious faulty conclusions.

Knowledge of the chronic effects of pesticides in man would be much greater if there were some way of studying them directly in man. Direct experiments of the type required to obtain the most relevant information, however, are excluded on many grounds.

The risk of exposure to pesticides is widespread. For example, in those engaged in the manufacture of pesticides as well as those who formulate and use them regularly. Persons who live or work in or near areas where pesticides are regularly used may be inadvertently exposed. Thus, symptoms of sensitization, gastro-intestinal, respiratory, nervous and ophthalmic manifestations have been observed in people living in contaminated areas.

III Soil Pollution

Magnitude and health significance

Solid wastes are generated from domestic, industrial and agricultural sources. For domestic waste, the per capita quantity of trash and garbage varies considerably from country to country depending on the level of economic development and sophistication. In metropolitan Los Angeles, for example, the total amount of solid domestic wastes in 1962 equalled about 1400 g. per capita per day as collected, or about 760 g. per capita per day on a dry weight basis. In contrast the total increment of solids between the water supply and the waste water collection system amounted to less than 200 g. per capita per day (dry weight). Hence, this metropolitan area rids itself of over three times as much dry weight by the solid route as by the liquid one. The annual operating cost for solid waste collection and disposal is about three times that for the handling of liquid wastes.

Solid wastes of domestic origin may be incinerated, composted, dumped on the land, buried or barged to sea. Each form of handling produces problems of public health. Burning and composting account for the organic wastes only and the ash or inorganic portion must still be disposed of. Incineration, even in the most efficient incinerators, causes air pollution, especially by nitrogen oxides. Composting and open dumping may increase the population of flies, rats and other vectors of disease. Buried organic wastes are subject to anaerobic decomposition and the production of methane and carbon dioxide may result in pollution of ground waters. Barging wastes to sea dumps may cause subsequent flotsam and beach pollution.

Industrial solid wastes have major economic implications but they are generally not a direct hazard to health. Exceptions can, of course, be cited. Major problems arise when solid industrial wastes are burned or ignite spontaneously, thereby adding to air pollution, or are allowed to be leached by rainfall with consequent pollution of surface or ground waters. The strip mining of coal, the formation of mountains of slag, and the tailings from mines all represent examples of solid industrial wastes defacing the land and rendering it unfit for many subsequent uses. Important problems develop from the need to dispose of radioactive wastes from reactors and nuclear research facilities by burial of solid wastes on land or at sea.

Solid agricultural wastes should not contribute to environmental pollution, for plant material is normally returned to the soil. The concentration of these wastes at transfer stations, canning or packaging plants, and produce yards, however, has created a problem. Here, huge accumulations of organic debris may decompose, leach from rainfall, attract disease vectors etc., with resultant pollution of the environment,

Chemical contamination of the soil

Chemical pollution of the soil results from the unintended or incidental contamination of the soil with man-made chemicals. The pollutants can reach man through the ground-water, the run-off or drainage water, and the plants used as food or forage for domestic animals - and to a smaller degree in wild life - serving as food. Therefore, the pollutants must be water-soluble and enter the soil moisture or the water percolating through the soil. Plants may draw their moisture from either source. Seeds dressed with pesticides may however be picked up by birds and harm them, and insoluble residues on vegetation may be ingested by cattle.

Genuine soil contains many inorganic and organic substances soluble in water. They are the products of the weathering and decay of minerals and the degradation of organic matter. By microbial action these substances are normally oxidized, in the main to inorganic oxides, but some organic compounds reaching oxygen-free ground-water may not be fully oxidized. Humus substances are found even in the best waters, together with small amounts of so-called trace elements. In nature, the soil gets some of its components from the air - e.g. the iodide from small droplet-nuclei generated by the seas - and from wastes from the burning of fossil fuels.

Fertilizers are intended to fortify the soil for the raising of crops, but incidentally may contaminate the soil with their impurities. Irrigation of farmlands and orchards may do this if the source of water is polluted by industrial wastes that contain synthetic organic chemicals.

During the last few decades, herbicides, insecticides, fungicides, soil conditioners and fumigants have produced intentional alterations of agricultural, horticultural and silvicultural soils. The chemicals used may accidentally pollute the soil water.

The soil must be regarded as a living community of fungi, bacteria, protozoa and metazoa. Fumigants and soil conditioners are unstable and metabolized by the microorganisms of the soil. For example, even the chlorinated phenol derivatives such as polychlorophenoxyacyl acids used as herbicides are metabolized by special strains of bacteria that adapt themselves to use them as nutrients. This holds true also for DNOC (dinitroorthocresyl) and allied compounds. It must be added that the bacterial and fungal flora of the soil is much richer in numbers than the flora of watercourses even when these are contaminated by organic matter. So it is quite possible that chemical compounds that can remain unchanged for a long time in water, may yet be rapidly degraded by microbial activity in the soil. It is known, for example, that by "feeding" a soil with chemicals such as phenols, bacteria that thrive on naturally occurring phenols will multiply.

Experience with new antibacterial drugs shows how effective some bacteria are in developing resistance to new substances. The metabolic enzymes undergo the necessary alteration so as to detoxify the compounds; we speak then of adaptive enzyme formation. By such mechanisms chemicals disappear from the soil, and farmlands must be sprayed every year with herbicides if weeds are to be kept in check.

Ideally only such chemicals should be employed that have been proved to be readily attacked and degraded by the common soil micro-organisms. Compounds of lead and mercury - the mercurials being mostly organic compounds - and salts of arsenious acids, are much more likely to accumulate as persistent soil contaminants and to introduce lead, mercury and arsenic into plant products.

The present trend in the manufacture of pesticides for use in agriculture is to synthesize short-lived degradable compounds because this minimizes the persistence of residues of pesticides and their degradation products on food and forage crops.

The only organic pesticides now in use which resist bacterial degradation and have no inert end-products are the chlorinated hydrocarbons, e.g. DDT, lindane, aldrin and dieldrin. Remnants of these stable pesticides appear to be bound to or adsorbed on soil particles which are made up of inorganic minerals coated with organic compounds. These chemicals may contaminate root crops grown in soils of this kind, for example lindane can taint carrots or beets. The behaviour of chemicals that do not affect the quality or reduce the yield of crops can escape notice, but true absorption and incorporation of these pollutants by plants is unlikely to occur in normal practice.

On the other hand, water seeping from soil contaminated by chlorinated hydrocarbons has been shown to contain small amounts of these substances. They are probably taken up by the lipid-containing humus of the soil and become part of the soil water. Possible, but yet not proved, is the absorption by man of such substances from drinking-water gathered from such soils. The presence of the substances has been shown by their extraction from the water by strong organic solvents. Amounts recovered are of the order of a few micrograms per litre. It is unlikely that they represent a toxic hazard to man in these amounts.

Observation of contamination of farmland in the neighbourhood of chemical factories has indicated that there is a potential danger of fall-out from the plume emitted by the smoke stacks of chemical works. However, this pertains only to inorganic contaminants. Synthetic organic chemicals are destroyed in properly operated stacks.

Whereas gaseous wastes enter the atmosphere and liquid wastes are generally discharged to surface waters, solid wastes are usually placed on or in the soil. Some solid wastes are dumped into surface waters with resultant water pollution and some are burned with conversion of much of the solids to gaseous wastes; on the other hand, some liquid wastes are spread on the soil and some are injected into sub-surface strata. The land environment, therefore, will receive most solid wastes and some liquid pollutants.

Research Projects

General

Research into environmental pollution should embrace both pure and applied research. Research is especially needed on the application of well-known principles to specific situations, particularly in the developing countries.

Pollution seems to be an inevitable consequence of modern industrial technology, rapid and convenient transport, and comfortable housing, but excessive pollution may interfere with man's health and his mental, social and economic well-being. The problem, then, is to determine the acceptable level of pollution, that is the level which permits optimal economic and social development without hazards to health in its broadest sense. This can be achieved by the systematic application of existing knowledge, supplemented by results from well-chosen research projects.

In reference to the newer organic synthetic chemicals, there is an urgent need for close study of man himself in relation to his ingestion of relatively small amounts of possibly dangerous substances over a prolonged period of time. Information based upon bio-assay through various aquatic organisms, as presently conducted, is not directly applicable to man. Fish, for example, can absorb and release toxicants without necessarily metabolizing them. Accidents, so useful in identifying levels of acute toxicity in industry, would not necessarily tell much about chronic poisoning. Current methods of testing for chronic toxicity on experimental animals are normally conducted on groups of animals which are relatively small when compared with the size of human populations likely to be exposed. Therefore, effects with a low incidence would go undetected. Moreover, studies on animals are not expected fully to reflect the effects of toxic substances on man. Synergism and additive effects of toxicants are possible and should be studied.

In the circumstances, it may be possible to adduce information from experience in industrial hygiene, especially when the toxicological data on which industrial standards have been based include animal feeding experiments as well as observations of the reaction of substantial populations at risk.

Epidemiological studies on groups of people with occupational exposures, or people living in areas of high exposure, should be undertaken to determine both subjective and objective signs of chronic toxic effects. Such studies should include measurement of pesticide and metabolite levels in available tissues - hospital specimens and autopsy material. These levels should be correlated with changes in enzyme activity, with changes in ophthalmic, auditory, neural, muscular and respiratory functions, and particularly with tissue levels associated with effects - or the absence of effects - in laboratory animals.

Although accumulation of pesticides in the tissues of man appears, from present knowledge, to stop when fairly low levels of storage are reached, prospective epidemiological investigations could be undertaken on the diseases caused by abnormal metabolism of carbohydrates or of lipids, on haemorrhagic coagulative diathesis, and on disorders of protein or mineral metabolism, in groups of people with high-level exposure to pesticides. Appropriate control groups would be essential.

Research into Mutagenicity and Carcinogenicity in relation to Air, Water and Food Pollution

Mutagenicity

Mutagenicity can have long-term effects of health significance in at least three ways:

Mutation of somatic cells may result in the emergence of new (non-malignant) cell types differing from the normal. If such cells are functionally less effective or interfere with the integrity of the organ, such mutations represent one form of pathogenesis.

Mutation of somatic cells is viewed by many as the mechanism whereby normal cells become malignant.

When non-lethal mutations are produced in the reproductive cells of the parent organism, genetic effects may occur in succeeding generations. The outcome is particularly important where large populations are affected by widely distributed environmental pollutants. Each chemical mutagen could contribute its quota of mutations to those arising from other sources. Accordingly the genetic consequences of all mutational factors must be evaluated jointly.

Many chemical agents are capable of producing mutagenic effects in one or another biological system. This, however, does not imply that such substances under conditions of actual exposure produce significantly frequent mutations.

Particularly active as mutagens are some of the alkylating agents, some of the so-called "anti-metabolites", and other chemicals structurally related to the bases of nucleic acid. Perhaps many compounds capable of modifying nucleic acid but still permitting replication may lead to mutation. A list of mutagenic chemicals including those which may occur in the human environment is included in an earlier WHO report (Wld Hlth Org. Techn. Rep. Ser., 248). The problem is more fully discussed there.

Tests of chemical agents for mutagenicity can readily be carried out on simple systems such as phage and bacteria. However, since entry, transport and metabolism are probably important factors in determining effective dosage of the mutagen, such minimal tests must be reinforced by study of these biochemical factors in higher organisms before an estimate of the likelihood of hazard can be ventured. Furthermore, some materials not in themselves mutagenic may be converted into mutagens by metabolism. For these reasons, the assessment of possibly mutagenic pollutants should be extended to mammals.

Population studies will no doubt be needed. They will, however, be extremely difficult, because of the problem of quantitating the effects in succeeding generations, and particularly because of the extreme difficulty in defining the actual exposure of the parents to the multiplicity of mutagenic factors.

Carcinogenicity

The extensive and well-documented history of occupational exposure ranging from the work of the chimney-sweep to the manufacture of chromium chemicals has established the reality and seriousness of the consequences of exposure to chemical carcinogens. Nearly every organ of the body is capable of yielding a tumour in response to an appropriate chemical agent. Although the responding tissue is sometimes that directly exposed, e.g. the lung with chromium chemicals or the skin with coal tar, on other occasions the tumour develops in a remote organ. An example of the latter is the occurrence of bladder cancer following exposure to certain aromatic amines, for which the chief portals of entry are the skin and the lungs. The effects of various routes of entry of chemical carcinogens are often additive, consequently the entire exposure pattern - water, air, food - needs consideration. An additional complication is that carcinogenesis from chemical agents is usually a consequence of the interaction of a number of factors. This is particularly well illustrated in the classical example of the two-stage mechanism of skin cancer induction. In this, a dose of polynuclear hydrocarbon, in itself incapable of producing cancer, leads to a high frequency of skin cancer if followed by the application of the promoting agent, croton oil, itself also without carcinogenic effect. Other modifying factors include prior disease (scar cancer of the lung), or infection (influenza virus and ozonized gasoline). In some instances simultaneous exposure to other toxic agents can impair the capacity for eliminating a carcinogenic agent. An example is injury to the clearance mechanism of the respiratory tract by tobacco smoke. In short, the assessment of effective carcinogenic exposures requires consideration not only of multiple sources, but also of the role of promoting factors.

The most decisive information on the hazards of chemically induced cancer in man has come from epidemiological studies on occupational groups. Studies on groups exposed to general community pollutants have not led to such conclusive results. Thus the role in the production of lung cancer of polynuclear hydrocarbons such as benzo(a)pyrene as an air contaminant is still uncertain. Although there is some evidence of a modest contribution to lung cancer from such sources, the issue cannot be resolved at present. A number of other air pollutants have attracted attention in this regard, among them non-aromatic organic compounds. The role of benzo(a)pyrene as an environmental pollutant has attracted much attention; it has been found not only as an air pollutant but in smoked foods and in soils, and is known to reach water supplies from several sources. Although its quantitative occurrence in such sources is of interest, such findings cannot be interpreted in the absence of information as to the relevance of the observed concentrations for man. The solution of such problems will require both epidemiological and laboratory studies.

Epidemiological studies have provided information on significant differences in the occurrence rates of tumours of various organs in different population groups. Such leads can guide the search for etiological factors if this initial information is reinforced by the development of adequate histories of exposure.

Laboratory procedures provide a useful adjunct to epidemiological studies in identifying causative factors. Such procedures, however, are particularly important as a means for predicting the likelihood of cancer from new materials prior to their use. There was a dramatic success in such predictive testing in the discovery that the compound acetylaminofluorene, which had been proposed as an insecticide, was a potent carcinogen. Despite such successes, however, the procedures now available are far from satisfactory either in reliability or convenience. Most of the accepted procedures for predictive testing involve the examination of moderately large groups of several species of animals over their life-span or a large fraction thereof.

Several factors limit the usefulness of such predictive tests. First, species differences have been shown to be decisive in many instances in determining tumour response. Species differences in metabolism of the carcinogen lead to differences in response, and mere use of more species may not be sufficient. Tests on laboratory animals thus invariably need reinforcement by parallel metabolic studies on man.

Second, the largest groups which can be used in most practical laboratory studies will be much smaller than the population groups exposed. Consequently, extrapolation from high to low incidence levels must be undertaken. On the one hand, the establishment of safe levels is difficult in the absence of general principles for such extrapolation. On the other hand, the approach based on the assumption of no threshold is possibly too conservative. Therefore, to assist the establishment of safe levels, a few large-scale experiments (involving large groups of animals) must be carried out to help in defining general principles for such extrapolation.

Third, in many instances secondary factors as noted above (disease, injury and so forth) may be decisive in determining hazard. Although it will obviously be impossible to examine routinely the large number of such possible variables, these considerations must be kept in mind in planning experimental work. Two suggestions emerge. The testing of realistic mixtures of substances in addition to the pure substances must be encouraged. Also, wherever possible, possible leads to relevant joint promoting factors should be taken into account in the planning of such studies.

A considerable number of short-term tests have been proposed for examining suspect materials for their carcinogenicity. These include sebaceous gland suppression, nucleolar enlargement, various responses in simple systems, for example tissue culture, slime moulds and paramaecia, and biochemical tests such as interaction with nucleic acid. Such tests have served useful roles in the examination of the comparative activity of compounds of a similar chemical type. All have, however, failed when extended to a wide variety of chemical structures.

In addition, these tests neglect the mechanisms of biochemical handling which may critically determine effective dose. These include efficiency of entry, storage and metabolism. Metabolic studies on man are a minimal requirement to reinforce the interpretation of the results of such accelerated tests.

Air pollution

Methods for research in air pollution

(a) Experimental studies. The development of quick simple methods for obtaining valid indices of pollution for use in epidemiological or other surveys is given priority by many workers. Of these methods, some lack specificity and their use can lead to erroneous conclusions. Methods for assessing particulate pollution by reference to the optical density of the stain produced on filter-paper require frequent recalibration in gravimetric terms. Instruments to record the concentration of pollutants at frequent intervals are desirable in order that the effects of sharp peaks in pollution can be evaluated. Because some plants and lower animals are more sensitive than man to low concentrations of certain air pollutants, they may be used as "biological indicators", that is as cheap and accurate complements or alternatives to complex measuring instruments. The danger of an uncritical application of the results from biological indicators to man's well-being must be recognized.

The investigation of exposure of human volunteers to realistic concentrations of urban pollutants separately and in mixtures is obviously preferable to experiments in which animals are subject to massive exposures. Although the investigation of the effects of realistic exposures on various aspects of lung function is of obvious value, experiments on other possible effects should be encouraged, for example it may be useful to investigate the effects on bacterial flora of the many particulate and gaseous contaminants found in urban air.

(b) Field studies. Adequate field studies can yield the most convincing indication of the association between mortality or morbidity and air pollution. Satisfactory studies, however, are dependent on accurate indices of health and of domestic and industrial pollution. They can therefore be carried out only in communities with facilities to compile such indices.

(i) Pollution indices. Whereas measurements of many different pollutants may be required for specific research projects, certain parameters should be chosen either by national or, preferably, international agreement for routine use. Furthermore, standardized techniques of measurement should be adopted. With standardized parameters and procedures, it should be possible to establish recommended sampling procedures for different types of areas, such as commercial centres of towns, areas of light or heavy industry, residential areas of different housing densities, and areas in which there is rigid enforcement of smoke-control regulations. In establishing these procedures regard must also be paid to the topography and natural ventilation of the areas. The results will, it is anticipated, facilitate comparisons between different types of areas.

(ii) Indices of mortality and morbidity. Suitable indices of mortality and morbidity must be carefully chosen. Certain segments of the community such as working men, soldiers, policemen, and in many countries children, are very healthy, and in consequence may be particularly resistant to the effects of air pollution. Indices such as these based on total numbers of deaths in the population, or on admissions to hospitals or on applications for sickness benefit have been found to be very sensitive in large communities. In smaller communities, however, random fluctuations may obscure the effects and other methods may be needed. Diary studies such as those used at the Medical Research Council's Air Pollution Research Unit, or the use of indices based on records compiled by general practitioners after first interviews with patients suffering from acute respiratory diseases, appear to offer the most hopeful techniques in such circumstances. In some communities, however, the population may be too small for satisfactory field studies.

(iii) Long-term effects of pollution. The long-term effects on man of pollution are generally recognized as being more important than acute reactions. Epidemiological research on this problem involves comparisons between different communities and consequently it is difficult if not impossible to exclude the effects of other factors. A critical attitude must therefore be adopted in dealing with the results of such studies. A positive association between chronic bronchitis and air pollution may be accepted, but that between cancer of the lung and air pollution is less certain; indeed any association appears to be slight in contrast to that between this disease and tobacco smoking. Further research must include prospective studies so that the incidence of these conditions may be correlated with future variations in air pollution.

(iv) The immediate or acute effects of air pollution. The immediate effects are more readily investigated by epidemiological techniques, and it is now possible to relate respiratory morbidity and general mortality quantitatively to specific levels of air pollution in certain communities. It may thus be possible to make comparisons between the acute effects of pollution in different communities and between different mixtures of pollutants in the same community.

(c) Certain specific problems for field studies. Among the more specific problems needing elucidation by field studies are the influence of acute outbreaks of respiratory infections on the health effects of air pollution, the effects on health of very short periods of high pollution, and an assessment of changing patterns of fuel use, especially in relation to the operation of very large power stations.

(d) Statistical and epidemiological methods in field studies. Epidemiology and statistics are becoming more and more effective in dealing with complexities of health data and surveys, and their potential must be reviewed periodically to determine which new techniques are available to improve the methodology of field studies of air pollution.

Water Pollution

Research into water pollution

During the past several years there has been a remarkable increase in many countries in the amount of research in water pollution. This research is being carried out by various governmental, university and private laboratories in many countries. Procedures for the sampling, recovery, identification and estimation of organic and inorganic contaminants are subject to frequent review and improvement, and new parameters for estimating degree of pollution are being tested. The evaluation of the effects of pollution on water quality by the study of benthon, plankton and other aquatic organisms and tests on their physiological, biochemical and ecological response to various degrees of exposure are being intensified; these studies may also lead to the identification of suitable biological parameters for simple evaluation of degree of pollution.

Epidemiological studies on the health significance of some biological agents and dissolved solids contained in polluted water which are partially removed by conventional treatment processes are still under way, and no definite conclusion can be drawn as yet. Research into improved methods for pollution prevention includes studies on the origin of various kinds of waste and assessment of the amount of pollution caused by urban and rural run-off. The recognition that, in many instances, conventional mechanical and biological processes fail to remove certain contaminants and that there is need for more efficient removal of potential pollutants from liquid wastes has led to research for new treatment processes, and a considerable amount of experience has already been accumulated in methods for separating a large variety of chemical, biological and radiological pollutants. In almost all instances this has entailed the application of known physicochemical principles, such as adsorption, electrodialysis, ion exchange, oxidation and others. Although the results of some of these new processes are promising, their cost is still a severe limiting factor, except for special intermittent operations.

Detailed reports on such research and related subjects are regularly published in various scientific journals and reports.

Current research

In research on the effects of pesticides, the concentrations of materials to be identified and determined are often very small - of the order of 1 pp 10^{11}. Identification and determination are possible only by the use of modern instrumental methods, of which gas-chromatography and infra-red spectrophotometry are examples. Thus expensive equipment is essential, as are the services of specialists trained in its use. To investigate the finer detail presented by the problem, even more sophisticated - and certainly more expensive - methods will be necessary. Clearly, few laboratories are at present equipped to carry out this type of analysis. Nevertheless, there has been rapid progress in the past few years.

With increased interest in the problem, it may be expected that this will continue.

In the United States of America, the realistic approach has been followed of considering the biocoenoses[1] of particular habitats and attempting to evaluate the effects of pesticides on the various links in the food chains which they represent. A similar approach is contemplated in the United Kingdom. It should be mentioned, however, that though the study of aquatic pollution has been going on for many years, this new problem involves a widening of the disciplines necessary to make up a well-balanced team. If fish-eating birds are the first members in the food chain to be significantly affected, for example, the team should include a field ornithologist. There is evidence also that many substances of importance are adsorbed on insoluble particles; they may then no doubt be ingested by bottom-dwelling invertebrates and so enter the food chain. Account will therefore have to be taken of the hydraulics of a river influencing the deposition and erosion of bottom deposits. Stagnant bodies of water (lakes, reservoirs) will require special consideration, because through stratification and sedimentation local accumulation of undissolved matters or solutes may occur, and also because dilution is a very slow phenomenon as depth increases.

It is well established that different organisms including fish are affected to greatly different extents by different synthetic organic pesticides. This obviously increases the complexity of the problem and much reduces the practicability of using any one species as a universal test organism by which the level of microchemical pollution in an environment and its ecological effects can be evaluated.

The complexity of the present chemical and physical methods for identifying and determining microchemical contaminants poses a particular difficulty where field studies are to be made in remote districts. Efforts are therefore being made to develop alternative procedures, particularly specialized methods of bio-assay. In this, notable progress has been made. There is a wide diversity

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[1] A biocoenosis is an ecological unit comprising both the vegetable and the animal population of a habitat.

of types of responses of organisms to sublethal concentrations of poisons, and it is believed by workers in this field that many biological responses can be used as a basis of bio-assay methods. These include, for example, growth of algal cells, rate of respiration, acquisition of avoidance responses, and level of fertility. There is some hope that with further development of this kind, it may become possible to measure not only the relative level of microchemical pollution of a water, but, at least to some extent, the nature of the contaminants concerned. Published works suggest that measurement of the effect of synthetic organic substances on the growth rate of algal cultures may yield useful information. Research on this subject is at present in a very active stage of development, and it is noted that premature standardization of bio-assay procedures or test organisms might hinder further progress instead of promoting it. Finally, it is emphasized that in order to establish efficient methods for detecting, identifying and monitoring microchemical pollution, there must be adequate baseline data on the ecology of the water systems concerned. This is seldom the case at present, and wherever circumstances allow, every effort should be made to collect such data.

Further Epidemiological Studies in Man

Much occupational health data, and experience on more than 350 substances have been used to develop standards for industrial exposures. Such information can be of considerable help in the selection of methods of research in air pollution and in choosing criteria for community air pollution standards. No general extrapolation of industrial air to community air standards should be made, because populations exposed differ greatly.

Use of occupational data for evaluating the hazards of community exposures. Much more information about the long-term effects of certain pollutants which occur in the general environment and also in higher concentrations in that of occupational groups could be obtained provided the records of such groups were better analysed. This requires closer co-operation between the industrial medical officer, the industrial hygiene engineer, the epidemiologist and the bio-statistician. To make the most use of this and other information, a uniform system of recording is required which will include changes of occupation, residence, period of sickness, and cause of death. This was formerly technically impossible on a national scale but may not be so now since the development of computers. It would thus be possible to follow prospectively the morbidity and mortality of groups with known exposure to particular pollutants or groups of pollutants. The establishment of, and access to, such records would be one of the most powerful epidemiological methods for the prospective study of a wide range of medical problems.

In the United States of America, Social Security Records (BOASI), which were not designed with this end in view, have proved their value in occupational health research, especially for cohort studies. In the United Kingdom, the Ministry of Pensions and National Insurance Morbidity Survey will enable a national study of occupation and of residence, and sickness from various diseases to be related to indices of pollution. In certain Scandinavian countries, extensive population registers have been maintained for several decades; they already include data on morbidity. This situation is well suited for carrying out additional epidemiological research.

Use of available hospital and clinical morbidity data. The long-term effects of environmental pollution on the respiratory system can be studied by better use of medical records in hospitals and health centres (in-patient and out-patient departments) as well as by pathological reports. A higher incidence of some communicable or infectious diseases among children and the working population has been reported in areas with higher air pollution. Further knowledge on prevalence of chronic inflammatory throat diseases and chronic bronchitis, as well as cor pulmonale, can be obtained in some localities from hospital admission and out-patient examination data. The possibilities of such research are not being fully exploited and ought to be encouraged. More explicit and uniform diagnostic criteria, both in clinical and pathological work, are needed as well as more precise and uniform data on exposure, including type and amount of pollutants, time and type of exposure, as well as demographic and other data on the population at risk.

The diseases to be followed should include, chronic throat diseases, chronic bronchitis, asthma, emphysema, pulmonary fibrosis, cor pulmonale.

Attention should be drawn especially to population groups under special health care, such as cardiac and emphysematous patients, and healthy groups under special preventive care, such as schoolchildren, pregnant women and athletes.

In these groups some special simple physiological studies should be recommended as part of routine follow-up examinations. The findings for areas with different pollution levels could then be compared.

This kind of work will be of greatest value when adequate environmental data are also obtained.

Behavioural studies. Much work on conditioned reflex and sensory physiological effects of pollutants has been carried out, particularly in the USSR. It has been suggested that such procedures in evaluating the long-term effects is probably limited. Some attempts to confirm these studies, particularly with respect to solvent vapours, suggest that the procedures are relatively insensitive. Further exploration should be made of the value of such procedures for both short-term and long-term exposures.

Prospective surveys for the evaluation of long-term effects of air pollution. Because of the complex and varying composition of air pollutants in different places and the possibly important effects of climate, it is desirable to carry out the epidemiological investigations on a larger scale and in more places than previously. To ensure that such results will be comparable and informative certain steps are essential: first, an adequate description of exposure, the second, a valid measure of medical effects, based on an adequate population sample, and third, a satisfactory follow-up method.

The investigation must be an ecological one, that is based on studies of both exposure and morbidity within a considerable number (hundreds) of districts. These districts should be selected to give the maximum variation in dose (exposure) and climate. Statistical design and population sampling can provide other criteria for selection.

When selecting districts for the investigations it will be necessary to make a preliminary study of the relevant variables in a considerably larger number of districts, particularly in respect of the concentrations of the most important pollutants and data available on the population structure.

The second problem concerns the measurement of effects. Detailed medical examinations of a population sample are not always feasible, and neither would it be satisfactory to rely on existing official statistics of morbidity and mortality. A study should be made, therefore, of the feasibility of using mailed questionnaires to obtain an estimate of the relevant information on respiratory and cardiovascular symptoms. Such an approach has already been tested in some countries and merits further exploration.

If a study of this type is to be practical, the requirements for completeness of information about all symptoms ought not to be set too high. Attention is called to the British Medical Research Council questionnaires on respiratory symptoms and those relative to angina pectoris along the lines of the questionnaire for field surveys, produced and standardized by WHO. The inquiries should be fitted into a model of the above-mentioned or some similar type - with as much consideration as possible for comparability in the evaluation of exposure and effect.

A check on the validity of the approach will be needed. This must be done by personal interviews and by a simple clinical lung function test ($FEV_{1.0}$) and environmental exposure estimates for a limited sub-sample of the populations and areas. Such methodological studies should be commenced as soon as possible, as pilot operations, along with training in the use of questionnaires, possibly including the use of tape recorders. Such pilot operations provide a means of testing intra- and inter-observer variability, and of selecting questions, and interviewers.

While the above procedures will permit additional estimates of prevalence, serial observations of two types may be useful in order to evaluate incidence. The first will consist of repetition of the same inquiry (mail or personal interview) and test using precisely the same methods and interviewers or examiners, if possible, and added to this, additional information about bouts of disabling respiratory disease should be obtained, if possible, from health records. Such a procedure also provides a means of evaluating interviewer variability. A second follow-up method consists of determining by comparison with official records the time and cause of disability, retirement or death. Such "death clearance" or "retirement clearance" studies are tedious if carried out by hand, but can be done on computers with greater facility.

Problems on which research is required

Environmental pollution in general

In outlining research on the health effects of environmental pollution, priority has been given to the total impact of air and water together, and where indicated with that of food and soil.

Greater efforts should be made to relate, both in breadth and in depth, the kinds and amounts of pollutants from all types of environments, with levels of pollutants and their metabolites in body tissues and fluids, and with health effects in man and animals using epidemiological and laboratory methods.

Better ways should be sought of facilitating more reliable extrapolation of experimental and animal data to pollutant effects on man.

The general problem of the means of the body's defence against pollutants, especially at low levels and the related problems of adaptation should be pursued vigorously, both in animals and in man.

The role absorption, distribution, storage and excretion play in pollutant toxicity should be more widely and thoroughly studied.

Increased research attention should be given to substances suspected of having carcinogenic, mutagenic or teratogenic effects.

Increased attention should be devoted to the study of effects of pollutants on ageing and life-span shortening.

Industry should be encouraged to consider, in the development of new products, not only their utility and safety in use, but also the likelihood of their contaminating the environment after they have been used, for example consider the biodegradability of detergents and the combustion products of plastics.

Characterization of pollutants. Characterization of environmental pollutants should be made: in regard to air, for organic compounds of sulfur and nitrogen, halogenated hydrocarbons and other halogen compounds, metals and metalloids with potential effects on health; in water, identifiable pesticides and metals and metalloids; in foods (and beverages) pesticides and the metal-metalloid spectrum.

Estimation of body burden. Systematic surveys should be carried out in many geographical areas of the metal, pesticide and other organic pollutant content of human tissue including blood and urine, with special attention to lead, cadmium and pesticides. Estimates of the environmental exposure to these substances from the air, water and food, from smoking and occupation, should be made simultaneously wherever possible. Similar data from wild and domesticated animals should also be sought.

Follow-up of heavily exposed populations. Controlled, long-term follow-up studies should be made among defined populations having unusually high exposure to pollutants which may affect the general community. These occur both in occupational groups and in local groups of the general population, such as those exposed to unusually high concentrations of lead (for example, traffic policemen), populations in the vicinity of metal refineries, populations in locations where the chromium level in the drinking-water is high, populations exposed to ozone in cold-storage plants and where ozone is used for odour control, mercury-exposed groups in and around alkaline chlorine plants, arsenic-exposed groups in communities where high-arsenic-content coal is used, carbon-monoxide-exposed groups in cities with high auto-traffic density and among workers in steel mills. The aim of all these studies should be to detect small deviations from normal function, using sensitive physiological and biochemical methods, as well as differences in morbidity and mortality.

Study of populations with unusual exposures to insecticides. Retrospective and especially prospective epidemiological studies should be made in groups exposed to unusual amounts of chlorinated hydrocarbon, organo-phosphates and other pesticides. One such population is in the vicinity of Ferrara, Italy. These investigations will be more valuable if they are co-ordinated with studies of the effects of pesticides on the fauna in the area. The studies should include possible chronic and indirect effects of absorption of the pesticides. Similar studies would be particularly appropriate in areas where intensive pesticide use is carried out in conjunction with malaria eradication programmes.

Development of postal questionnaire methods. A feasibility study should be made of a cross-sectional survey of respiratory and cardiac (and possibly eye and skin) symptoms using a standardized mailed questionnaire in a large number of population groups in different countries. The areas chosen should have large differences in pollution and climate. Standardized measurements of pollution will also be required and a system will be needed for interviewing a sample of the population to check the validity of the mailed questionnaire, and to confirm the histories of exposure.

Possible relationship of cor pulmonale to pollutant exposure. Further international comparisons should be made in selected hospitals of the proportion of the admissions with cor pulmonale, and of its incidence at autopsy. Standardized criteria will be required for diagnosis in life and at autopsy.

Intensive study of epidemic respiratory allergies. Episodes of local air pollution, suspected of being related to "epidemic respiratory allergies", should be investigated.

Uniform occupational exposure data. The long-term effects on health of pollution (and of all other environmental factors) require for their solution a continuity of information about the individual and his environment over a life-time. Countries should be encouraged to develop uniform and comparable records and make them accessible for health research so as to pool information on occupation, residence, sickness and death of individuals and population groups.

Standardization of observations

Standardization of laboratory methods. The development and standardization of methods of laboratory investigation should be concerned with at least five problems: (i) wider use of new analytical methods for pollutants; (ii) development of mathematical models for estimating integrated doses of pollutants; (iii) comparison of methods of measuring physiological and biochemical responses to pollutants; (iv) development of new measures of response; (v) rapid screening methods for identification of health hazards associated with new chemical pollutants.

Standardization of epidemiological methods. Reference centres should be designated to develop, test and standardize epidemiological methods for investigating long-term effects of pollutants. Initial attention should be given to questionnaires, both personal and postal, for studying respiratory reactions to pollutants. Such centres should also train personnel in standardized methods, develop standard methods for measuring exposures in the populations studied, and, through contact with field operations, maintain comparability between studies.

Animal experiments

Experimental exposures to realistic pollutant mixtures. Animal exposures should be performed using realistic mixtures and levels of air pollutants and simultaneously using water and food which contain realistic amounts and types of contaminants. Among the observations which should be made are those of toxicity, effects on social behaviour and effects on ageing and life-span.

Large-scale experiments. For purposes of improving the reliability of extrapolation of low prevalence events for predicting human health hazards, the use in selected experiments of large numbers (thousands) of animals is recommended.

Effects of pollutants in combination with infection. Selected experiments should combine pollutant exposures with exposures to infectious agents, both naturally occurring and experimentally introduced. Studies should also be carried out in animals with specific organ impairment or general debility.

Epidemiological studies in animals. Epidemiological studies of pollutant effects should include the natural environmental receptors of pollution and wild and domesticated animals, in the latter case through cooperative veterinary research. Work on development of new inbred strains and new species of animals for laboratory investigation of pollutant effects should be intensified.

Enzyme studies

Role of enzymes in adaptation to pollutants. Further steps should be taken to determine which pollutants stimulate the production of adaptive enzymes in animals and man, with special attention to repetitive stimulation, as part of an over-all effort to understand the defence mechanism of the body against pollutants. Differences in response in different host species and strains should be determined; the effects of age on these relationships should be evaluated. Research on the mechanisms of these changes is also needed.

Immunological reactions to pollutants. Research should be continued on the immunological responses to pollutant exposure and on which pollutants have important effects in this respect, as well as the effects of pollutant combinations on the immunological process. Research should be continued and expanded on the immunological effects of infection, deliberate and natural, superimposed on pollutant exposures.

Other adaptive mechanisms. Investigations should be made on the ways in which the central nervous system contributes to the maintenance of homeostatic equilibrium and thus to defence and adaptation to pollutant exposures. Efforts should also be made to find ways of improving the natural defences against pollutants and the adaptation mechanisms of the body.

Metabolism of absorbed pollutants

Investigations should be extended on the absorption, distribution, metabolism, storage and excretion of environmental pollutants; this should include such routes of entry as skin, respiratory and gastro-intestinal tracts. The studies should be focused on compound groups or types, for instance, the carbamates, or other newly introduced pesticides, the epoxides, the more important aromatic amino and nitro compounds, alkyl nitrosamines, and other substances with carcinogenic, mutagenic or teratogenic potential, certain halogenated substances, aerosol combinations and metals and metalloids.

Carcinogenic and mutagenic studies

Research on the carcinogenic and mutagenic potential of pollutants should be directed to the effects of five factors: (i) route of entry; (ii) metabolic transport; (iii) species differences; (iv) promotors or accelerators; (v) dose-response relationship. Research on determining teratogenic effects should be initiated with the object of determining the lowest dose of the agent from water or air pollutants which will result in effects.

Long-term pollutant effects on ageing

Research on ageing or life-span shortening effects should

a. screen pollutants in order to determine whether such effects are likely, and the dose-response pattern;
b. determine the processes by which these effects occur; and
c. attempt to establish criteria for defining the ageing process.

A list of the research problems given in this section together with other investigations proposed by the Scientific Groups and their recommendations to WHO are given in "Research Problems in Environmental Pollution".

Members of the Scientific Groups on various aspects of environmental pollution which met in Geneva during the period March 1963 to November 1965

Microchemical Pollutants in the Environment (March 1963)

Members:

Dr J. M. Barnes, Director, Toxicology Research Unit, Medical Research Council Laboratories, Carshalton, Surrey, United Kingdom

Professor P. Bonnevie, Director, University Institute of Hygiene, Copenhagen, Denmark

Professor Gordon M. Fair, Professor of Sanitary Engineering, Harvard University, Cambridge, Mass., United States of America

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Dr M. Hollis, Director, Division of Environmental Health

Dr M. Laird, Chief, Environmental Biology

Mr R. Pavanello, Chief, Air and Water Pollution

Scientific Group on the Biological Estimation of Water Pollution Levels (1-5 June 1964)

Members:

Dr H. Bick, Zoologischen Sammlung der Landwirtschaftlichen Fakultät der Universität Bonn, Bonn, Germany

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Dr B. J. Cholnoky, National Institute for Water Research, Grahamstown, South Africa

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Professor H. Liebmann, Bayerische Biologische Versuchsanstalt (Demoll-Hofer-Institut), Munich, Germany

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Scientific Group on Biological Aspects of Microchemical Pollution of Water Systems
(8-12 June 1964)

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Scientific Group on Research into Environmental Pollution (20-25 July 1964)

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Scientific Group on Long-Term Effects on Health of New Pollutants
(10-16 November 1964)

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Scientific Group on Identification and Measurement of Air Pollutants
(16-22 November 1965)

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No. 13	Aspects of water pollution control	1962
No. 15	Epidemiology of air pollution	1962
No. 23	Urban water supply conditions and needs in 75 developing countries	1963

Technical Report Series

No. 10	Expert Committee on Environmental Sanitation, Report on First Session	1950
No. 47	Expert Committee on Environmental Sanitation, Second Report	1951
No. 77	Expert Committee on Environmental Sanitation, Third Report	1953

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No. 144	Procedures for the Testing of Intentional Food Additives to Establish their Safety for Use (Second Report of the Joint FAO/WHO Expert Committee on Food Additives)	1958
No. 157	Fifth Report of Expert Committee on Environmental Sanitation - Air Pollution	1958
No. 213	Chronic Cor Pulmonale (Report of an Expert Committee)	1961
No. 233	Expert Committee on Filariasis ...	1962
No. 246	Occupational Health Problems in Agriculture (Fourth Report of the Joint ILO/WHO Committee on Occupational Health)..............	1962
No. 248	Radiation Hazards in Perspective (Third Report of the Expert Committee on Radiation)...........	1962
No. 271	Atmospheric Pollutants - Report of a WHO Expert Committee	1963
No. 285	Expert Committee on Hepatitis	1964
No. 292	Environmental Change and Resulting Impact on Health (Report of a WHO Expert Committee)	1964
No. 297	Environmental Health Aspects of Metropolitan Planning and Development (Report of a WHO Expert Committee)	1965
No. 318	Water Pollution Control (Report of a WHO Expert Committee)	1966

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WORLD HEALTH ORGANIZATION

ORGANISATION MONDIALE DE LA SANTÉ

ANNEX II

WHO INTERNATIONAL REFERENCE CENTRES

CONTENTS

1. INTRODUCTION

This document deals with WHO International Reference Centres (IRC) and Regional Reference Centres (RRC) and their relations to each other and to National Reference Centres (NRC). These three types of centre together form an important world-wide network of institutions with the aim of promoting the use of specific standards in materials and practice and of developing research and collaboration on problems arising from the reference work of the centres.

Many types of reference centre are included among the international activities and responsibilities of WHO. Their variety is too great for a comprehensive statement about them all, however brief. A general statement should, however, be helpful for those concerned with them.

2. DEFINITIONS

(a) An International Reference Centre (IRC) is an institution designated by WHO, or by competent and specialized international bodies, to assist in the development and maintenance of high standards of work in specialized fields, where such are needed.[1] An IRC provides certain services of international value to practice or research in medicine and public health.[2] The aim of these services is to achieve improved precision, reliability, consistency and comparability in practice, and better results from national and international studies.

(b) A Regional Reference Centre (RRC) has responsibilities similar to those of an IRC but restricted to those it is fitted to accept and limited to a group of geographically related countries.[3] It collaborates with the IRC in its field by collecting certain data and materials, assisting in the development of classifications, etc., and has closer contact with NRCs for consultations. It deals with inquiries from NRCs and passes on to the IRC only those problems that it cannot resolve. It is established by WHO in consultation with the IRC. Usually there is only one RRC in a region. If there are no RRCs there is direct communication between NRCs and IRCs.

[1] There are joint WHO/FAO IRCs for subjects of interest to both organizations, e.g. brucellosis, leptospirosis.

[2] No useful distinction can be made, in connexion with IRCs, between services to practice and services to research.

[3] The term "regional" is used here for a geographical grouping which is not necessarily equivalent to a WHO region.

(c) A National Reference Centre (NRC) is established by a government to provide consultant services in a particular field, and it is responsible to the government alone. An NRC may establish direct contact with the related RRC and, in the absence of an RRC, with the IRC. The NRC is entitled to receive, upon request from the RRC or IRC, samples of standard materials and related information on the methods of use of such standards. It passes these on in turn to other national institutions (NI) and industries. In the absence of either an RRC or an NI, an individual worker or a scientific or industrial institution may communicate directly with an IRC and may receive on request standard or reference materials from the IRC if sufficient are available.

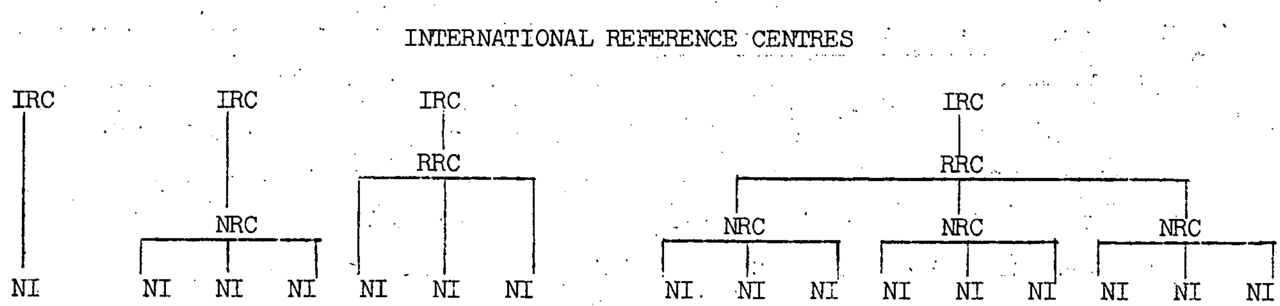
(d) WHO collaborating laboratories may be of several kinds:

(i) A laboratory may be selected by an IRC, in agreement with WHO, to work exclusively with the IRC for perhaps a year or two on some task requiring international collaboration.

(ii) A laboratory may be selected by WHO in agreement with an IRC to work with the IRC for a few months on checking proposals for an international classification, nomenclature, etc., before the IRC presents it to WHO.

(iii) A laboratory may be selected by WHO to work directly with the Organization for a certain period in collecting information or materials, or in carrying out certain reference duties more limited than those entrusted to a designated reference centre.

The following diagram suggests the relationship between RCs:



3. DENOMINATION

The name in most general use is "International Reference Centre", although sometimes "Laboratory" is used instead of "Centre".

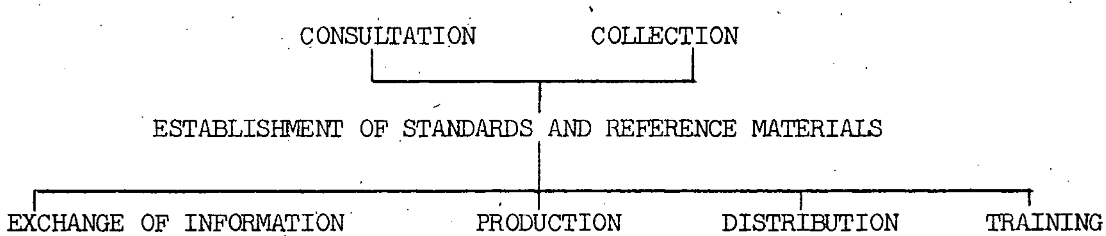
If an International Reference Centre has been designated by WHO it should carry the words "World Health Organization" or the initials "WHO" before it. "Reference" has the meaning of "submission of a matter to some authority for discussion or information", and "consultation" is also implied. Although in some instances "laboratory" might have a more specific meaning than "centre", in general it is restrictive and for this reason the word "centre" is preferred. Thus the generic name would be "WHO International (or Regional) Reference Centre for . . . .".

It may be undesirable to change the names of long-established reference laboratories but future reference institutions should be designated "ICRs" or "RRCs" as far as this is reasonable.

4. PURPOSES AND DUTIES

(a) Purposes

The purposes of the IRC are to perform and develop services to practice or research in medicine or in public health. These may be indicated diagrammatically in the order in which their activities often develop:



(i) Establishment of standards (upon request of WHO)

Designation of particular materials to serve as international standards or as reference preparations (and definition of international units). The development of standard nomenclatures, classifications, or minimal requirements for biological substances, lists of normal or permissible levels of toxic substances in the body or of potentially harmful radiation, standard (uniform) techniques, methods, etc.[1] recommended for international use.

The general procedure for this work, especially in nomenclatures and classifications, is that an IRC serves as a co-ordinating centre on behalf of and responsible to WHO. It should not make or publish any interim or final statement on these without the consent of WHO.

In cancer pathology, for example, with the help of an advisory group of experts from different countries and representing different academic traditions, a tentative classification, standard, etc., is prepared. This is then studied by the IRC and several collaborating laboratories. The proposals arising therefrom may be sent for a few months to other collaborating laboratories for checking before their presentation by the IRC to WHO for recommendation for international use, with or without submission to a WHO advisory group. Related competent specialized international bodies may be consulted at the initial stage of the above procedure and for the subsequent promulgation of the standards. The development of international nomenclatures, classifications, standard reference materials, etc. is usually an activity of limited duration. When this has been completed - after a year or more - the IRC may become a centre for international consultation, if the head of the centre agrees. The work of the collaborating laboratories may then be regarded as ended except that it may be practical to use some of the former collaborating laboratories for training, after consultation with WHO.

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[1] WHO is interested in, and responsible for, establishing international standards for the determination of potency and international requirements for the quality of biological substances, as well as recommended specifications for pharmaceuticals and other substances, materials, etc. It cannot, however, assume wider responsibilities for the quality of materials commercially produced than to recommend that they be tested for conformity to the recommended requirements and specifications. Batches, after testing, can be stated to conform or not, but statement of conformity cannot be considered as "WHO approval" for the product.

A standard is an authorized exemplar (model for imitation) of a unit of measurement, e.g., the former standard metre. A biological standard is established to specify a biological property, e.g., potency, in terms of a unit, as for instance, units of insulin. The term "standard", however, is often used in the sense of "uniform", e.g., standard method.

The main purpose of the development of standard nomenclatures and classifications is to increase the comparability of the studies of population groups in different countries. Thus a nomenclature or classification can usually be regarded as satisfactory for this purpose if it provides for 90 or 95 per cent. of the situations in which it will be used.

Nomenclatures and classifications must, before final acceptance by WHO, be thoroughly studied to reduce variability both between different specialists (inter-observer variability) and by the same specialist on different occasions (intra-observer variability), in order to determine their suitability for general use. It is better to have fewer but less highly specified terms with higher intra- and inter-observer comparability than to have more and very specific terms and less comparability.

(ii) Consultation (upon request of RRCs or, in their absence, of NRCs or of WHO)

(1) Identification of strains, organisms, parasites, vectors, tumours, etc.

(2) Checking of accuracy and consistency of technical methods, etc.

(3) Control of other recognized standards relevant to the IRC.

(iii) Collection, production and distribution of materials (upon agreement with WHO and upon request from RRCs or NRCs)

(1) Reference or standard strains of organisms, insects or animals, normal or abnormal, for specific purposes.

(2) Reference or standard materials, sera, reagents, histopathological preparations, frozen tumours, kits, etc.

This work is based upon the acceptance of international standards and international reference materials and may continue indefinitely. However, excessive demands on the services of the IRC should be avoided by the work and screening of the RRCs and NRCs. The costs involved in these activities, e.g. distribution, are provided for by the WHO payment to the IRC.

(iv) Exchange of technical information (a routine duty)

Periodical reports should be made to WHO of the work proposed in the Letter of Designation and technical service agreement and of other relevant technical data, such as strains of organisms identified and details of their sources[1] and material collected and distributed. Data from them will be distributed by WHO to relevant RRCs, NRCs and other interested institutions and workers. The preparation of manuals may be necessary.

(v) Training (upon request of WHO or governments)

There is increasing need for the training of WHO fellows and research training grantees and other trainees. Training may start at an IRC at any time after its designation but it is preferable to start it after a classification, technique, etc. has been established. It may be undertaken in RRCs or collaborating laboratories with adequate facilities. Before a fellowship or research training grant is awarded by WHO for study at an IRC or arrangements for other trainees are made, acceptance of the prospective trainee by the centre must be obtained.

(b) Duties

The duties of the IRC and the activities of the host institution should not be confused. The duties of the IRC must at all times be directly related to the purpose for which it was designated. The host institution will almost certainly carry out research and have clinical facilities and a library; it will also perhaps be entrusted with epidemiological or other responsibilities by the national health authority. These are not necessarily among the duties of an IRC or RRC which has assumed international or regional responsibilities for other relevant duties. However, in certain scientific fields the close interest of the head of the IRC or RRC in the material received at the centre has led to a broader approach to new problems involving further collaborative and co-ordinated research among the IRCs and RRCs.

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[1] Often only atypical and unrepresentative strains are sent to the IRC.

5. REPORTING BY WHO-IRCs AND WHO-RRCs

Periodical or annual technical reports on the work done should be submitted to WHO. These may be distributed by WHO to other interested institutions (see 4(iv)). Reporting the presence and spread of a disease in a country is usually the responsibility of the national health authorities.

6. CRITERIA FOR SELECTION OF AN IRC

(a) Subject

In the designation of a WHO-IRC for a particular subject, a major criterion is the need, due to absence or inadequacy, of standard materials, classifications, nomenclatures, reagents, etc. for international purposes. The present or future importance or prevalence of the condition not already adequately studied, geographical differences of prevalence, and the needs of WHO programmes should be taken especially into account.

(b) Locality

The choice of locality depends upon the presence of a suitable research institution and the availability of, and ready access to, material. If there is more than one suitable institution for a particular subject, geographical position should be taken into account and the concentration of IRCs in a few countries should be avoided.

(c) Institution

The most important single criterion in the choice of institution is the availability of a man or woman of outstanding professional capability in the proposed subject, who will serve as head of the centre and who, with the institution, will be responsible to WHO for the IRC; his acceptability to other workers in the field concerned is also essential to ensure their co-operation. An IRC cannot be designated until the head of the centre is known and the consent of the director of the host institute has been obtained.

Other supporting factors which must always be ensured before the designation of an IRC include: availability of other qualified professional staff; active relevant research in the host institution; certain basic facilities, such as laboratory space, technical and clerical staff, equipment, animal supplies (if necessary), distribution resources, etc. The location of related designated and planned regional and national reference centres will also be taken into account.

In selecting an institution to be designated as a WHO-IRC careful consideration should be given to the probable continuity of the responsible specialist officers. It is, however, important that the IRC should not be dependent solely upon one particular person if it is to continue with functions other than those of definition. In other words, the proposed host institution should be sufficiently large or important to ensure the continued activity of the IRC even if the key person should cease to be in charge of the IRC or other specialist staff be changed. In the past, when a post which included that of the head of an IRC has had to be filled, the host institutions have often kept in mind the duties of the IRC.

The final selection of priority, subject, and institution and the definition of the precise duties of the WHO-IRC are made by the Director-General.

7. DESIGNATION

When the Director-General has approved the establishment of a WHO-IRC in a host institution, the approval of the director of the latter is sought. At the same time the government is informed of WHO's intention to designate the centre. Only after the director's approval has been received is a letter of designation sent to the head of the future RC. This letter clearly states the duties and responsibilities of the centre and also WHO's responsibility towards the centre, including any annual payments to be made by WHO and the probable period of such support. A formal technical services agreement between WHO, the director of the institute, and the head of the RC, confirms this arrangement on forms WHO 362 and 363, and is renewed annually, as required, on the same forms.

When a WHO-IRC with consultant and training duties has been designated, all WHO regional offices are informed and are requested to notify the governments in their region of this designation, the duties of the centre, and the services available from it to RRCs and NRCs.

The designation of IRCs with consultant duties will also be reported in the WHO Chronicle with a statement of the services available to NRCs.

8. RESPONSIBILITIES OF WHO TOWARDS WHO-IRCs AND WHO-RRCs

Financial support

WHO's financial contribution to an IRC or RRC is intended solely for the work of the reference centre. The WHO payment is intended to assist in the provision of such items as additional equipment, technical, clerical or professional assistance; facilities for training; packing and distribution of materials and information; and any other expenses directly related to the work of the centre; it is not intended to replace any of the existing financial support received from the host institute.

WHO payments to WHO-IRCs and RRCs are generally for one year only. Continuing future support may be foreseen, subject to availability of funds, but this does not imply any commitment on the part of WHO. A new agreement is negotiated for each year.

Co-ordination between RCs

For better co-ordination of the work, it may sometimes be necessary for WHO to convene meetings of directors of WHO-IRCs and of WHO-RRCs.

9. RESPONSIBILITIES TO WHO-IRC OF HOST INSTITUTION

The host institution will provide to the WHO-IRCs, free of charge, laboratory accommodation and basic equipment, basic services, and staff (which should already be available). This will be agreed with WHO in correspondence before the designation is made.

ANNEX III

SUPPLEMENTARY INFORMATION FROM WMO ON AIR POLLUTION

I. INTRODUCTION

The problem of air pollution has three main aspects :

1. The phenomenon itself : the sources of pollutants and their measurements, the dispersion of contaminants in the atmosphere, the physical conditions under which the dispersion is possible or impossible, the self-cleaning mechanism of the atmosphere, the variations in the concentration of the pollutants, and so on. To learn more about the phenomenon of atmospheric pollution would obviously lead to a deeper understanding of the problem and a better knowledge of how to combat its effects. Without this understanding all efforts would be in vain.

2. The consequences of air pollution, of which the most important directly affect living conditions and human health. But apart from these, there is another consequence, the significance of which, for its effects on human life, most people do not realize - namely, pollution-induced change in weather and climate. For example, atmospheric pollution on a small scale both in time and space, may reduce visibility, which could in turn affect many human activities. Large-scale atmospheric pollution may reduce solar radiation received at the earth's surface, through the surrounding atmosphere; this, in turn, may bring about an important change in the temperature regime of the atmosphere. The effects of the eruption of Krakatoa, in August 1883, were powerful enough to be felt for over three years; they included mean summer temperatures some 2° to 3°C below the normal for the month. Recent research in the Main Geophysical Observatory of Leningrad has shown that the average amount of solar radiation received has been gradually decreasing since 1940. This may also be attributed to the increasing pollutant-content of the atmosphere.

3. Prevention of air pollution. The problem here is two-fold and can be stated briefly as follows :

(1) Prevention of air pollution in regions where sources of pollution already exist (especially in major industrial areas).

To this end we should perhaps consider the following possibilities :

(a) Application of new techniques (filters, very high chimneys, etc.) in order to reduce the degree of air pollution as much as possible.

(b) Emission of pollutants into the atmosphere only when meteorological conditions permit, as for instance when a high degree of turbulence makes for rapid dispersal.

The first possibility (a) is of a purely technical nature whereas the second (b) requires the application of special meteorological knowledge, both theoretical and experimental. It also requires accurate information only obtainable from special meteorological measurements. It is necessary for this purpose to forecast meteorological conditions in order to know the outlook for the dispersal of the pollutants into the atmosphere some 8 to 10 hours ahead, or even more. Once again, such predictions require special meteorological knowledge and cannot be made in a routine way.

(2) Prevention of air pollution (or at least minimize it) in new industrial areas, now being planned or to be planned in the future.

Here we should mention that before any new industrial areas are planned - or any new single plant, microclimatological studies should be made of the specific area. These preliminary studies will help determine the zone to be included in the planning area. The selected area must then be tested in order to locate in appropriate places all likely sources of pollutants and so to find the optimum solution ensuring adequate living conditions within the specific industrial area planned before any construction scheme is undertaken.

The report of WHO deals mostly with the second aspect of the problem, although the first and third are given good coverage; however, we feel that recent meteorological developments in the field of air pollution warrant some further discussion.

Therefore, WMO's contribution on this particular subject includes some additional considerations which may promote a better understanding of the problem as a whole in the light of new developments.

II. THE SOURCES OF AIR POLLUTION

Many essential activities in the developed and developing countries cause atmospheric pollution. The main sources are house-heating, generating of electric power and elimination of waste; they also include specific industrial installations which may be factors in the pollution of specific areas but these factors may vary from one region to another and from one time to another, as well (this point is very important). The increasing magnitude of air pollution problems within the community result from new economic developments, such as industrial complexes as well as new residential areas.

In regions where the concentration of motor vehicles is high more sustained attention is required to the air pollution caused by the internal combustion engine (including the Diesel engine), which often assumes considerable concentrations. Increasing energy requirements have led and are still leading to a more rapid growth in the consumption of Diesel fuel, for generators. The aggravation of air pollution by sulphur dioxide which may occur together with soot and smoke can also be associated with the increasing energy requirements. It is quite obvious that efficient combustion practices can minimize the latter but not the former.

There are, of course, many other sources of pollutants, the so-called "natural sources" in which we may include volcanic eruption, cosmic dust, salt from sea water (after the evaporation of the small sea water droplets), smog from forest fires, carbon dioxide from various natural sources especially from trees at night time, etc., to name but few.

Scientists believe that the amount of pollutants from natural sources is rather small comparatively to that from human activities but this is more an assumption than an evident acknowledged fact in the present state of our knowledge.

III. AIR POLLUTION MEASUREMENT

Air pollution measurement is well covered by the WHO report and there is little to add. However, a few words may be in order on the measurement of pollutants <u>outside</u> polluted areas. For this purpose some so-called background stations should be established. These stations could provide information, by means of continuous measurements, on the general level of contamination of the atmosphere and determine long-term changes in the chemical constituants of the atmosphere. About 50-100 background stations would be sufficient for the world-wide coverage of both ocean and land areas. With regard to land station density, each country might establish one or two background stations to conduct measurements of contaminants at global levels. Furthermore and according to the size of the country other stations could later be added to make the same kind of measurements but at regional levels. These background stations could be located as far away as possible from large urban and industrial plants and should be free of any influence from small, local sources of air pollution. The programme of work for background stations should include weekly average concentrations of sulphur dioxide from air samples as well as the concentration of the major constituants S, Cl, NO_3 - N, NH_3 - N, Na, K, Mg and Ca from monthly precipitation samples. Measurement of carbon dioxide concentration at a few selected sites where representative values could be assured, would also be desirable. The actual analyses could best be carried out by a few analytical centres.

IV. RADIOACTIVE POLLUTANTS

The discovery of atomic energy, the invention of the atomic bomb and, in particular, nuclear weapon tests, have faced humanity with the important problem of preventing contamination and pollution of the atmosphere. The danger has become quite understandable not only to the scientist but to the general public. Since this discovery much theoretical and experimental research has been carried out. The most important results of the combined efforts of scientists in various countries are described below :

(a) Thanks to the large amount of theoretical study carried out, it is now possible to describe some processes of turbulent diffusion in our atmosphere by mathematical formulae. On the basis of modern mathematics new theories have been worked out; these include the theory of pollutant diffusion into the turbulent atmosphere, the theory of turbulent atmospheric flow round obstacles, and so on. With modern electronic computers, it is possible to use these theoretical models, in some cases but unfortunately not in all, and to observe and calculate the behaviour of the contaminants and pollutants emitted from isolated point sources, and even from extended area sources, into the atmosphere.

(b) The equation of turbulent diffusion has already been found. At present it serves as a basic equation for theoretical investigations in this particular field of research.

(c) The formation of particles in nuclear bomb debris has been considered and the task of following up these formations after a nuclear explosion involves long and intricate computations. The difficulties are increased when results are not widely distributed, being withheld for purely national interests. Consequently, the research worker has to content himself with mere evaluations and may have to go on contenting himself with these same approximations in the future.

(d) The mechanism of the transport of radioactive particles and debris as well as of the other contaminants has also been studied approximately. It is considered that the wind is the main factor in the transport of particles and debris. It has now become possible to calculate the size of the afflicted regions, by the special techniques developed for the purpose.

(e) Some work has been done on radioactive dust washout from the atmosphere. Sutton's well-known diffusion formula was used as basic equation; but it has since been modified to yield the deposit due to washout and, as a result, two formulae have been derived from it, one for instantaneous point sources and the other for continuous point sources. Using these two formulae, suitable for either assumed or actual conditions, estimates can be made of the hazard due to deposited material or to the depletion of airborne clouds by removal of radioactive material.

V. METEOROLOGICAL CONDITIONS AND AIR POLLUTION

The meteorological conditions (most of them are mentioned in the WHO report) which influence the dispersion of atmospheric pollutants may be combined in formulae for the calculation of concentrations. However a distinction should be made between :

(a) Point sources, such as isolated chimney stacks; and

(b) Area sources, such as large urban communities.

In both cases it is the wind speed, wind profile, wind structure (turbulence), atmospheric stability and the roughness of the ground surface, that are the most important factors in determining the dispersion of pollutants. In most cases these factors are used qualitatively only. This is true especially of wind structure, atmospheric stability and the roughness of the ground surface. These three parameters are interrelated to some extent. With respect to point sources, the existing qualitative methods for forecasting concentrations expected under various meteorological conditions can be regarded as useful. The effect of vertical wind shear is not included in these methods and improvements might be obtained by the introduction of this effect.

Another shortcoming is the lack of a complete theory concerning the rise of hot plumes in the atmosphere. There is a feeling that a thorough testing of existing theories would be very useful. A further difficulty for the computation of concentrations originating from point sources lies in the relations between maximum concentrations and sampling times. A number of studies - most of which are theoretical - have been devoted to this problem and it might be useful to append a survey of present-day theories.

The problem of estimating the pollution level in cities is much more important and complex owing to increasing urbanization all over the world. The same factors that determine the pollution level of a point source are applicable although the roughness of the terrain is naturally more important. Information on wind profiles and stability in cities is, as a rule, less readily available than for rural regions. Every possible effort should be made to see that this information is as complete as possible. Stability can also be inferred qualitatively from diurnal temperature variations, as well as from wind and cloud observations.

In principle, pollution concentration in cities can be determined with order of magnitude accuracy, by use of computers to apply one of the existing point source models to the various sources in the city and to add the results. Such a procedure is only possible, however, if all source strengths of the city blocks are known. A better estimate of the effects of the roughness of the terrain and the effects of traffic would also be desirable. The most important objection to the method is, however, that all point source models fail during situations with weak and variable winds and it is especially under these circumstances that the air of a city shows large concentrations of pollutants.

Another possibility would be to investigate under what general meteorological conditions (characterized, for example, by circulation types such as those which have been defined for Central Europe by Hess and Brezowsky) high concentrations occur in urban regions. This semi-empirical method has been investigated in a number of countries and it is thought that it might be helpful in identifying meteorological conditions conducive to high pollution levels. Here again the problem is that concentrations vary with sampling times. According to some computations made, concentrations in large cities tend to increase proportionally with the square root of time after a sudden increase in stability. Although this result was confirmed by the evolution of the air pollution level during the great smog in London (December 1952), it would be worthwhile to gather information on the correlations generally found between concentration and sampling time in cities.

VI. FORECAST OF AIR POLLUTION

Two kinds of air pollution forecasts are now recognized, namely :

(1) Climatological forecasts for engineering design and town planning; and

(2) Synoptic forecasts for short-term alerts.

The usefulness of synoptic forecasting at present is limited in most countries because no legal machinery exists to enforce a reduction in emission when unfavourable meteorological conditions are forecast. However, forecasts are valuable in some countries for alerting various agencies and encouraging voluntary control. National health authorities may realize that many national Meteorological Services are in a position to assist them in making forecasts of high pollution levels. Some examples of this forecasting assistance are given below :

In the Netherlands, critical pollution levels are attained only three or four times a year, and so it is not easy to forecast pollution levels on a routine basis. Municipal agencies continuously monitor the sulphur dioxide concentration and, when it rises beyond a certain level, they ask for the guidance of the meteorological service.

In the United Kingdom, different types of forecasts are issued. One of the London Hospitals is provided with a special forecast when the Meteorological Office expects a concentration of sulphur dioxide in the vicinity exceeding 1000 microgrammes per cubic metre. This local forecast is based on an empirical formula that has the following variables :

(a) The intensity of the low-level inversion,

(b) The night minimum temperature,

(c) The wind speed,

(d) The amount of cloudiness.

If smog conditions are expected to persist for about 24 hours, a warning of persistent fog is issued to the public and they are advised to manage their coal fires in such a way as to minimize smoke emission.

In the United States, forecasts of "pollution potential" are made with the assistance of electronic computers at the National Meteorological Center "pollution potential" being the dispersion and ventilation capacity of the atmosphere whether pollution sources are present or not. These forecasts are based on a system which uses radiosonde lapse rate, rawinsonde average, winds in the lower layers, and "mixing depth" - the latter being related to a forecast of maximum temperature. Sometimes, when the synoptic scale meteorological conditions are correctly forecast, local influences, such as terrain features and lake-land breezes, cause ventilation and high levels of pollution do not occur.

In many countries (including Canada, the Netherlands, Sweden, U.K., U.S.A. and the U.S.S.R.) meteorological services are asked for advice concerning location of new pollutant sources. Climatological forecasts are made by relating the emission rate and the height of the chimney to the atmospheric dispersion factors and the climatological wind distribution. In this regard it would be very useful for more climatological studies to be made of dispersion factors.

VII. SELF-CLEANING OF THE ATMOSPHERE

There is no doubt that there exist self-cleaning processes in the atmosphere, though not much is known about them. This is at present a notable gap in our knowledge of air pollution as a phenomenon. However, we know something about chemical processes which can clean the air. We also know that the dust in the atmosphere may very slowly descend under the force of gravity, and we also know something about the processes of washout by atmospheric precipitations. But even this knowledge is very limited. Particular attention should therefore be paid to the study of self-cleaning processes of the atmosphere. If we gain such knowledge we shall be able to be more efficient in the prevention of most of the consequencies of air pollution.

VIII. PLANT INJURY BY AIR POLLUTION

Plant life is greatly influenced by a number of air contaminants, some of which may be present in the atmosphere in relatively low concentrations. The susceptibility of different species and even of different varieties of one sort of plant may vary considerably. However, surveys have shown that the economic losses, both direct and indirect, caused by air-pollution injury to agriculture are extensive and are increasing in many parts of the world. To deal adequately with this particular aspect of pollution the WMO Commission for Agricultural Meteorology has set up a special working group which is mainly concerned with plant injury and reduction of yield by non-radioactive air pollutants. Among the items dealt with in the first report of this working group we may point out the following :

The study of plant injury by air pollution is rewarding not only in itself but in its application to various other air pollution problems. The fact that some species of plants may be injured by certain contaminants of concentrations too low for ready detection by present instruments or chemical analysis is of value in identifying such contaminants. Zimmerman* remarks that plants may be affected by ethylene at concentrations as low as one part per 100 million, detection of which by chemists is extremely difficult.

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* Zimmerman, R.E., 1952 : General Session on Agricultural Panel, Proc. of the United States Technical Conference on Air Pollution, McGraw Hill Book Co., New York.

The symptoms on plants have frequently been the first indication of an air pollution problem in an area. Since vegetation does develop characteristic readily-recognized symptoms when exposed to low concentrations of certain air pollutants, it can serve as an indicator of air pollution and as a useful tool for field surveys. However, because the response of a plant to a given concentration is highly dependent upon a host of environmental factors, vegetation is not always a good monitor of air pollution.

Field surveys of vegetation have a definite place in the assessment of an air pollution problem. The limitations of such surveys are obvious but often ignored. The first limitation is in our ability to recognize and identify the effects of only about five major pollutants : sulphur dioxide, fluoride, ethylene and two members of the smog complex. Secondly, we are dependent upon the existence of susceptible varieties, in a susceptible stage of growth at the time of exposure to concentrations sufficient to affect them. Thirdly, a competent observer must be in the field at the appropriate time to observe the symptoms after development and before the symptoms have been obscured by other changes. We must always keep in mind that vegetation is a receptor of variable response depending upon a host of prior conditions. The observation of injury identifiable as due to a specific pollutant may demonstrate the existence of a significant air pollution problem. Failure to identify such symptoms does not necessarily mean that a significant air pollution problem does not exist.

Plants also have a useful role as monitors of air pollution. The limitations are somewhat similar to the problems in using plants as a survey tool. We often think of using either specific native or specially planted plants as a monitoring instrument. Yet if we do not take into account all the factors which can change the response of the plant - the instrument - to the pollutant, our data will not be reliable. In order to provide reliable data, the plant monitoring system requires careful servicing and protection, and the data derived must be interpreted from a full understanding and evaluation of all the factors which could influence response. It is no different than any other monitoring instrument in this respect.

The use of plants as tracers of atmospheric transport and dilution is of interest to the meteorologist. Observations of plant damage and meteorological conditions assist in identifying sources. This is particularly useful when damage is cumulative (as for example, fluorides). When source emissions, plant damage and meteorology are all known, estimates of dilution mechanisms can be formed.

Effects of pollutants on plant growth and productivity

Suppression of growth and reduced productivity of plants by air pollution is due in great measure to the ways in which contaminants affect the physiology of the plant itself. These injuries interfere unfavourably with some or all of the normal processes (such as photosynthesis, respiration, transpiration, cell permeability, etc.) essential for plant growth.

Photosynthesis is a process by which organic matter is produced from carbon dioxide and water with energy from light. Reduction in the efficiency of photosynthesis results in less photosynthetic products, which constitute all the dry matter and product of the plants. According to Todd et al*, duckweed (Lemna minor) fumigated (i.e. exposed to pollutant) with 0.2 ppm. of oxidant** (ozonated hexene) were visibly injured and their photosynthesis was reduced by about 10% after four hours, and 67% after 24 hours of exposure. Chlorophyll destruction which might inhibit photosynthesis was 4% and 49% respectively. Duckweed fumigated with 1.0 ppm. of ozone resulted in 5% reduction in photosynthesis after four hours, and 38% after 24 hours exposure. Chlorophyll reduction was 5% and 40% respectively. This suggests that the type of oxidant may be a factor in the reduction of photosynthesis and ultimately plant growth and productivity. The same authors found that fumigation of lemon fruit with oxidant resulted in accelerated respiration, the process by which organisms utilize photosynthetic products to release energy for use in other vital processes. It is not known just how harmful is such stimulation of respiration, but it certainly does result in unnecessary consumption of carbohydrates. Erickson and Wedding***, who carried out experiments in which they fumigated Lemna minor with ozonated hexene, state that "the inhibition of photosynthesis was related in some way to the increase of permeability and ultimate death of the cells, and yet the degree to which photosynthesis was reduced was far greater than the change in conductivity".

According to Taylor****, transpiration essential for plant growth and development was reduced by about 25% when lemon cuttings and lemon scions were fumigated with artificial smog.

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* Todd, G.W., Middleton, J.T., and Brewer, R.F., July 1956; Effects of Air Pollutants, California Agriculture Vol. 10, No. 7, pages 7-8.

** In all comments on oxidant concentrations, the values are referenced to the neutral buffered potassium iodide method of measurement, expressed as ozone.

*** Erickson, L.C. and Wedding, R.T., January 1956 : Effects of Ozonated Hexene on Photosynthesis and Respiration of Lemna minor. Am. Journal of Botany, Vol. 43, No. 1, pages 32-36.

**** Taylor, O.C., 1958 : Air Pollution with Relation to Agronomic Crops : IV Plant Growth Suppressed by Exposure to Air-Borne Oxidants (Smog), Agronomy Journal, Vol. 50 : 556-558.

Growth of tomato, alfalfa and endive seedlings subjected to natural smog was reduced even without discernible leaf lesions. Tomato seedlings fumigated for three hours daily with artificial smog also showed no visible injury, but suffered a 49% reduction in growth rate during the first day following fumigation as reported by Hull and Went*. Taylor** reports that several varieties of bean leaves suffered almost complete destruction after being fumigated for one day with 0.15 to 0.20 ppm. of oxidant, while petunia subjected daily to synthetic smog showed only slight leaf injury, although its rate of growth during three weeks exposure was reduced to almost half, and the blossom initiation was completely suppressed. Similar results were obtained with natural smog, but with less damage intensity. Sixty per cent of tomato blossoms failed to develop in natural smog, while plants kept in carbon filtered air had fruit for nearly all blossoms. When Lisbon lemon cuttings were fumigated daily with 0.15 to 0.20 ppm. of synthetic oxidant for three months, the fresh weight of the portion above ground was reduced by about 31% and the dray weight by about 35% without ever showing typical smog injury, although chlorosis developed after about two months. One hundred thirty-three leaves of the fumigated plants dropped, but only fourteen leaves were lost from those kept in unpolluted chambers.

Suppression of plant growth by sulphur dioxide is due solely to the destruction of leaf tissue and the subsequent loss of an effective area to continue photosynthesis. According to Thomas***, as a first approximation of the few crops investigated, reduction in yield, expressed as percentage of the yield of an uninjured crop, varies linearly with the percentage of total leaf area damaged at the time of fumigation. For alfalfa this seems to hold true with fumigation at any stage of plant growth, and the effects of multiple fumigation are additive, whereas for wheat, barley, tomato, corn and cotton, the reduction in yield seems to depend rather on the stage of development of the plant at the time of fumigation. There was little effect on barley yield with fumigation at the early stage of plant development, but a 40% reduction in yield, with all the leaves being destroyed, resulted from fumigation at the "boot" to "milk" stages. Wheat yield reduction with complete defoliation at the time of fumigation varied from 8% during the seventh week to 35% during the tenth to fourteenth weeks of growth. Reduction in wheat yield was almost negligible when grown in soil sufficiently fertile.

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* Hull, H.M., and Went F.W., 1952 : Life Processes of Plants as Affected by Air Pollution, Proceedings of the Second National Air Pollution Symposium, Los Angeles 17, California, U.S.A., pages 122-128.

** Taylor, O.C., 1958 : Air Pollution with Relation to Agronomic Crops : IV Plant Growth Suppressed by Exposure to Air-Borne Oxidants (Smog), Agronomy Journal, Vol. 50, pages 556-558.

*** Thomas, M.D., 1958 : Air Pollution with Relation to Agronomic Crops : I General Status of Research on the Effects of Air Pollution on Plants - Agronomy Journal, Vol. 50, pages 545-550.

Studies of the effect of sulphur dioxide on conifers are reported by Katz and McCallum*, who report that trees with injured leaves were found three years later to have a relatively smaller growth of foliage. Severely injured trees suffered partial killing of limbs. Both Douglas fir and yellow pine showed a decreased in height growth, the former to a greater extent, for about three years after being treated with sulphur dioxide, after which they recovered substantially.

Extensive damage to a variety of plants can be caused by hydrogen fluoride. According to Todd and Garber**, growth suppression occurs only with visible injury as a result perhaps of loss of photosynthetic capacity. Considerable killing of leaves of several varieties of grapes, and a subsequent reduction in growth resulted from fumigation with 10 ppb. (parts per billion) of hydrogen fluoride for a 30-day period. Gladiolus plants subjected to the same fumigation suffered a decrease in flower production. Thomas and Hendricks*** report that abscission of leaves of fruit trees such as apple, apricot, plum, prune, peach and fig can be as high as 25% to 50% when half the leaves are injured with hydrogen fluoride, occasionally with subsequent loss of fruit in the first year and failure to set fruit in following years. Adams et al**** found that injured needles of ponderosa pine grew to only three-quarters their normal length if the injury occurred before they were fully grown and that they had a shorter life span.

Acid aerosols and toxic mists produce small to large spots on the upper surface of leaves and cause damage to fruit, while solid particles such as carbon and cement dust are sometimes responsible for soiling of fruits and vegetables.

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* Katz, M. and McCallum, A.W., 1952 : The Effect of Sulphur Dioxide on Conifers, Air Pollution - Proceedings of the United States Technical Conference on Air Pollution, Chapter 8, pages 84-94, McGraw-Hill Company Inc., New York.

** Todd, G.W., and Garber, M.J., December 1958 : Some Effects of Air Pollutants on the Growth and Productivity of Plants, The Botanical Gazette, Vol. 120, No. 2, pages 75-80.

*** Thomas, M.D. and Hendricks, R.H., 1956 : Effect on Air Pollution on Plants, Air Pollution Handbook, Chapter 9, pages (9-1) - (9-44) McGraw Hill Book Company Inc., New York.

**** Adams, D.F., Mayhew, D.J., Gnazy, R.N., Richey, E.P., Koppe, R.K., and Allen, I.W., 1952 : Atmospheric pollution in the Ponderosa Pine Blight area, In. Eug. Chem. 44, pages 1356-1365.

Crops toxic to man and to animals may be produced if the soil is contaminated with materials like lead or arsenic. Productivity is also likely to decrease in such soil. Uptake of lead from the soil by plants has been detected by Professor H.V. Warren of the University of British Columbia, and by Miss Helen Cannon of the U.S. Geological Survey. Only 10-75 ppm. were found in plants under normal conditions, whereas in plants grown near major lead ore deposits the lead concentration increased to 4,000 ppm. High values were also found in plants grown in a city "smog" atmosphere, and in areas within 50 ft of a main road. The latter is believed to be due to car exhaust pollution.

The papers of Guderian et al* and Treshow** give excellent summaries on recognition and evaluation of effects, and Landau and Brandt*** discuss the problems of assessing economic loss. Dugger et al**** and McCune et al***** present some of the problems of assessing physiological and biochemical responses. Some of the problems of evaluating the influence of other environmental factors on the response of plants to air pollutants are discussed by Heck et al******.

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* Guderian, R., H. Van Haut, and H. Stratmann, 1960 : "Probleme der Erfassung und Beurteilung von Wirkungen gasförmiger Luftverunreinigungen auf die Vegetation", Zeitschrift Pflanzenkrankheiten, Bd. 67, S. 257-264.

** Treshow, Mr., 1965 : J. Air Poll. Cont. Assoc. 15:266

*** Landau, E. and Brandt, C.S. : J. Amer. Statistical Assoc. (in press).

**** Dugger, W.M., Taylor, O.C., Thompson, C.R., and Cardiff E., 13(9) September 1963 : The effect of Light on Predisposing Plants to Ozone and Pan Damage, J. Air Poll., pages 63-87.

***** McCune, D.C., Weinstein, L.H., Jacobson, J.S., Hertagh, A.D., and Hitchcock, A.E., June 1965 : Paper No. 65-99 58th Annual Meeting APCA, Toronto, Canada.

****** Heck, W.W., Dunning, J.A., and Hindawi, I.J., 1965 : J. Air Poll. Control Assoc. 15:511.

The overall economic loss from plant injury by air pollution is unknown and perhaps even impossible to obtain, since apart from losses incurred by destruction of plants there are a number of direct and indirect losses which it is hardly possible to estimate. For example, the extent of reduced growth is not known. A small but perhaps significant reduction in assimilation occurring before recovery cannot be evaluated; effects of solid particules and their direct effect upon vegetation is of some concern, but little is known of the subject. It might, perhaps, at times be possible to give a rough indication of the losses arising merely from destruction of plants in specific instances. Brandt* gives a loss of 6-10 million dollars annually for California, in the Los Angeles region. However, he remarks that "the estimate does not include the possible growth effects, the value of produce in backyard gardens, the loss in ornamentals, or other marginal effects". Darley et al** estimate that there is an annual loss of more than 25 million dollars annually in the U.S.A. Thomas and Hendricks*** give losses to cotton in Texas, as a result of spraying rice fields, at least 15-20 miles from the nearest cotton field, as 200,000 dollars. In Canada, millions of pounds of flue-cured tobacco have been rendered commercially valueless as a result of oxidant pollution, being more than six million pounds in 1957. The bulk of this loss occurred on about one-third of the total tobacco acreage. One farmer lost two-thirds of his crop, while several others lost one-third to one-half of their crop.

Although extensive observations have been taken and much progress made, the fact remains that our present understanding of this subject leaves much to be desired. There are many phases of air pollution problems in which our knowledge remains deficient. Neither the identities of most airborne contaminants nor their exact effects on vegetation are as yet known. Moreover, the development of visible injuries - recognizable necrotic and/or chlorotic patterns - are not fully identified with

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* Brandt, C.S., 1962 : Effects of air pollution on plants. Air pollution Vol. 1, Chapter 8, pages 255-281, Academic Press - New York.

** Darley, E., Dugger, W.M., Mudd, J.B., Ordin, L., Taylor, O.C., Stephens, E.R., 1963 : Plant Damages by Pollution derived from Automobiles. Archives of environmental health, Vol. 6, pages 761-770.

*** Thomas, M.D. and Hendricks, R.H., 1956 : Effect on Air Pollution on Plants, Air Pollution Handbook, Chapter 9, pages (9-1) - (9-44) McGraw Hill Book Company Inc., New York responsible air pollutants. On the other hand, certain contaminants are known to produce less well-defined responses in growth rate, flowering, fruit set and other physiological upsets. This type of injury is more widespread than was commonly supposed. The readily discernable lesions may be only a general indication and not a true measure of the total damage by pollutants to vegetation. Other deficiences arise from a lack of reliable and precise instrumentation capable of sampling and analyzing the various chemicals and measuring the essential meteorological parameters involved.

IX. ACKNOWLEDGMENT

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