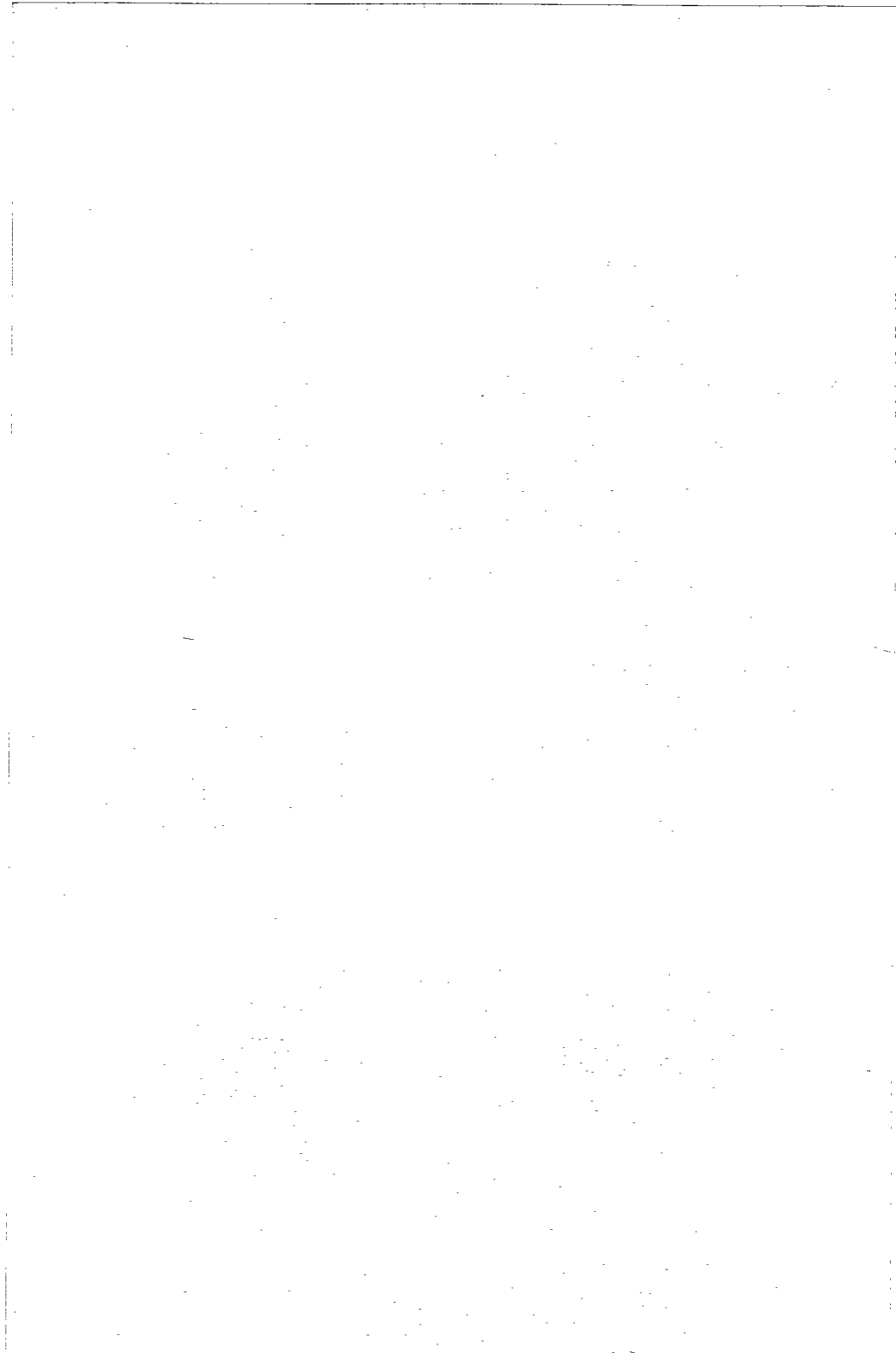


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EPIDEMIOLOGY OF AIR POLLUTION

Report on a Symposium



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PREFACE

Although air pollution, in one form or another, affects many parts of the world, it is of special significance in Europe, where large populations are subjected to the health hazards and the economic losses with which this social evil is associated. Europe is also in a key position with regard to research on this subject, for many countries in this region are investigating the problem and some important advances have been made. In November 1957, the WHO Regional Office for Europe sponsored a conference in Milan on public health aspects of air pollution in Europe, the first meeting of its kind to be held in this continent. This conference was immediately followed by a meeting in Geneva of the WHO Expert Committee on Environmental Sanitation, which discussed a wide range of air pollution problems on a world basis. In 1959, the Regional Office for Europe began a detailed study of the problem in collaboration with organizations in all European countries having interests in air pollution research and control. It became clear that there was a widespread but rather uncoordinated interest in the epidemiology of air pollution and it was decided to arrange an international meeting for a discussion on the lines along which epidemiological and related research might usefully develop. The Symposium that was the outcome of this decision was held in Copenhagen on 13-16 December 1960, and was attended by participants from fourteen European countries, including the authors of the present report.

INTRODUCTION

Air pollution has been described as one of the worst environmental evils to which the peoples of Europe are exposed. Although in some areas current methods of control are resulting in cleaner air, in others air pollution is increasing both in the chemical complexity of its composition and in the extent of the areas affected. Motor traffic is the cause of growing anxiety in many areas because of the emission of carbon monoxide, of lead compounds, and of polycyclic hydrocarbons with suspected carcinogenic properties. Air contaminants are also discharged in wide variety in many chemical and other industrial processes and may be responsible for local problems of a specialized character. The Symposium, however, was primarily concerned with the general pollution of urban areas resulting from the use of domestic and industrial fuels, of which the most frequently used indices are dustfall, suspended matter, and sulfur dioxide.

Researches on air pollution are being undertaken in a number of countries, but many authorities consider that the scientific effort at the present time is too small in relation to the complexity and urgency of the problems involved. It has been suggested that one reason why more support has not been given for this work is that the full pathological effects of air pollution have not yet been evaluated. Often these effects are not recognizable as diseases peculiar to polluted atmospheres but appear as exacerbations of certain common diseases. Until recently, the extent of the exacerbations has not been capable of assessment, but new epidemiological techniques have yielded results which some authorities regard as something in the nature of a "break-through". One of the important objectives of the Symposium was to discuss these new techniques and their potentialities in relation to European air-pollution problems.

THE NATURE OF AIR POLLUTION

The degree of air pollution to which different populations are exposed cannot be expressed in terms of a single index. Air pollution in different localities is caused by mixtures of a wide variety of solid, liquid and gaseous substances, some of which may be harmful to health while others are innocuous. The study of the relationship between air pollution and disease therefore requires the evaluation of specific impurities.

The identification and measurement of these impurities involves the use of specialized sampling and analytical techniques. In the planning and execution of epidemiological studies of air pollution the co-operation of medical, chemical and other experts is important, and instruments and analytical facilities should be adequate to ensure that medical observations of the effects of pollution are matched by equally reliable data on the nature and extent of the pollution associated with those effects.

The value for epidemiological purposes of detailed measurement of pollution is shown by recent experiments in the United Kingdom demonstrating the striking day-to-day correlation between mortality and morbidity data on the one hand and the concentrations of sulfur dioxide and black suspended matter on the other, as discussed in more detail later in this report. These observations appear to provide some of the strongest evidence so far available of the harmful effects of air pollution on the public health. It is not yet possible, however, to draw definite conclusions as to the nature of the contamination responsible for the observed effects because of the tendency for the concentrations of all air-borne pollutants to increase or decrease simultaneously, but the results of similar experiments conducted in other areas where the composition of air pollution was different should help towards identifying the causative factors. Comparative investigations in areas with very different relative concentrations of suspended matter and sulfur dioxide would be of particular interest.

It was suggested that experiments such as these showing the day-to-day relationship between bronchitis morbidity and certain pollutants may provide a possible basis for keeping air pollution down to levels that will not exacerbate the disease.¹ It should be possible in each area to determine separately the threshold concentration of, say, sulfur dioxide or black suspended matter, above which daily changes in morbidity parallel changes in pollutant concentration and below which they do not. This would not necessarily imply that the pollutants actually measured were themselves responsible for the observed effects, but that their concentrations varied in accordance with those of other pollutants, including the causative agents.

THE SIGNIFICANCE OF COARSE PARTICLES

The particulate pollutants of the atmosphere occur in a wide range of sizes. Dustfall, mainly composed of particles coarser than 10-20 microns, is a form of pollution recognizable by the unaided senses and capable of evaluation by simple instrumental techniques. It has therefore been accepted by some authorities as a convenient general index of air pollution. However, during normal breathing most particles larger than 10-20 microns are retained in the nasal passages and only finer material enters the lungs, although mouth breathers may inhale more of the larger particles. Some participants in the Symposium stressed the advantages to epidemiological investigations of using the simplest possible measurement techniques, and suggested that dustfall is often an index of industrial activity, and thus of the probable presence of other pollutants. Other participants did not accept dustfall as an index of pollution that could be expected to correlate with respiratory disease, and after discussion there was agreement that it should not be recommended for this purpose.

Photomicrographs indicate the heterogeneous character of air-borne suspended matter. For example, samples from the London atmosphere include micron-sized carbonaceous particles—mostly in the form of aggregates and chains—fragments of fuel and ash, droplets of tar and acids and a variety of crystalline substances. In other areas with different sources of pollution the composition of the mixture, and its effects, will differ. Such chemical and physical differences between air pollutants must be associated with different pathological effects; a better understanding of the nature of suspended matter, which may be obtained by optical and electron microscopy, by micro-chemical analysis, or by other techniques, is clearly needed.

¹ Wilkins, E. T. (1960) *Air pollution measurements and their use in epidemiological studies* (unpublished working paper).

ACIDS

Sulfur dioxide is one of the air pollutants most commonly measured, but, although it undoubtedly does much damage to materials, opinions differ as to its pathological effects at the relatively low concentrations in which it occurs in the atmosphere. Some authorities attach more importance to the irritant effect of sulfuric acid aerosol which may result directly from the combustion of coal or oil or from the oxidation of sulfur dioxide in the atmosphere, but relatively little is known about the amounts of this substance present in the atmosphere of towns, or about the sizes and acid-strengths of the droplets.

Oxides of nitrogen, particularly nitrogen dioxide and nitric oxide, may occur in appreciable concentration among the products of combustion. They are chemically reactive and of possible pathological significance.

A theory proposed to account for the irritant effects of even low concentrations of air pollutants postulates a "synergistic" effect between the irritants themselves and relatively inert suspended solids. On this theory sulfur dioxide gas, for instance, becomes adsorbed on to the surface of the solid particles as a layer more concentrated and more irritant to mucous membranes than the gas itself. The practical significance of this lies in the fact that, while it is technically difficult to control the emission of sulfur dioxide, it is relatively easy to control the emission of solid particles, so that reducing the amount of solids in the atmosphere might also reduce the ill-effects of sulfur acids. Up to the present, the validity of this theory has not been confirmed.

OTHER POLLUTANTS

Carbon monoxide, produced mainly by motor vehicles, is an increasing hazard in many countries, and toxic effects have been observed, particularly on traffic policemen. Some authorities maintain that even concentrations of this gas normally considered safe for industrial workers are capable of having harmful effects on a proportion of the general population. The possibility that lead compounds emitted by motor vehicles may also be injurious to the health of city dwellers is causing uneasiness in some countries. Many countries are currently engaged in the study of benzpyrene and other suspected carcinogens found in the air. Motor vehicles have been thought by some to be major sources of benzpyrene, but it is now known that the incomplete combustion of coal and fuel oils can produce much larger quantities of benzpyrene.

THE MEASUREMENT OF AIR POLLUTION

Most European countries make some measurements of air pollutants; but these are generally restricted to a few areas and a large proportion relate only to dustfall. The information generally available on sulfur dioxide and suspended matter is too meagre to permit an accurate assessment of the extent to which European populations as a whole are exposed to these pollutants, but there is no doubt that in many areas where measurements have been made, the concentrations of these pollutants are comparable with those that have been observed in the United Kingdom to be correlated with variations in mortality and morbidity. The possible existence in parts of continental Europe of hazards to health due to air pollution and comparable to those in some areas of the United Kingdom cannot be ignored. There is an urgent need for more surveys of air pollution in European countries, co-ordinated where possible with epidemiological research projects.

STANDARDIZATION OF METHODS AND TERMINOLOGY

The need for standardized methods of sampling and measurement and for a greater uniformity in terminology is now generally recognized. Several countries in Western Europe are represented on a working party of the Organization for Economic Co-operation and Development which is studying methods of measuring air pollution and survey techniques, with particular reference to the standardization of methods for measuring sulfur dioxide and suspended matter. Progress is also being made in standardizing methods used in Eastern Europe, and WHO has a detailed programme for securing on a world basis greater uniformity in nomenclature, instrumentation, analytical techniques and methods of handling the data relating to air pollution.

MEASUREMENT TECHNIQUES

Sulfur dioxide

Four variants of a simple empirical method are widely used in Europe for determining average levels of pollution by sulfur dioxide. This method involves the absorption of sulfur dioxide by a chemically active substance (lead dioxide or alkali) which is exposed to the atmosphere for between one and four weeks and then analysed for its sulfur content. This procedure is widely used because the apparatus is inexpensive and needs no source of power and no attention during the period of exposure. The results so obtained, however, are seriously affected by factors other than sulfur dioxide (e.g., by wind speed) and can only be expressed in empirical units and not in terms of atmospheric concentration. Unfortunately, no other method is generally available for the determination of averages over long periods except the averaging of daily values.

For the determination of average concentrations of sulfur dioxide over periods of from a few hours to a day or two, the hydrogen peroxide method is widely used in Europe. In this method air is sucked through a solution of peroxide and the sulfuric acid so formed is determined by acidimetric titration or, in some instances, by the turbidimetric estimation of precipitated barium sulfate. This method, though not completely specific for sulfur dioxide, is generally subject to only minor inaccuracies. For shorter periods of sampling the tetrachloromercurate (TCM) method has been found to be specific for sulfur dioxide and to be generally satisfactory.

Some participants in the Symposium favoured the empirical methods employing lead dioxide or alkali because of the cheapness of the instruments required and their ease of operation. Others considered these methods subject to major errors rendering them unacceptable for epidemiological purposes. Participants in the Symposium generally agreed that the hydrogen peroxide method was the more satisfactory for epidemiological studies. There is a need for improved methods of measuring sulfur dioxide and other air pollutants over very short periods, particularly in the study of peak concentrations. Automatic sequential samplers and continuous recorders are particularly useful for this purpose but these are expensive and sometimes delicate instruments and, for most of the epidemiological work in prospect, a number of suitable instruments of simple construction will generally give more useful information for the same outlay than a single more complex recording apparatus.

Suspended matter

Current methods of measuring suspended matter depend on the filtration of a given volume of air and the direct or indirect evaluation of the sample so collected. When taking large-volume samples over a short period there appears to be no difficulty in the direct gravimetric evaluation of the sample. For continuous sampling, generally at lower rates of air flow, gravimetric methods have sometimes been found to present difficulties arising from the small weight of the sample, the hygroscopic properties of the filter and of the sample itself, and the general laboriousness of this method. An alternative method widely used for many years depends on the fact that samples of suspended matter are usually almost black and so appear as a grey stain on white filter paper. This method involves a photoelectric assessment of the reflectivity of the stain, the result being expressed as a concentration on the basis of previous calibration. Thus, whereas the direct gravimetric method records the total of suspended solids, the reflectivity method is probably valid mainly for the black component of the sample.

It is not possible at present to choose finally between the two methods. The unsatisfactory features of the reflectivity method are generally recognized and may become still more marked as the composition of suspended matter changes in response to smoke-abatement measures. On the other hand, the value of the reflectivity technique for epidemiological purposes has been established in the British bronchitis investigations mentioned, and it would seem prudent not to discard it at least until the value of alternative methods has been assessed more critically.

SAMPLING

In determining the pattern of air pollution over a heterogeneously polluted area, some investigators have used large numbers of sampling instruments. In other surveys aimed at determining average values, the area has been divided into zones having different air pollution characteristics and each zone has then been monitored by only a few instruments. For the purposes of international co-operation in epidemiological research there will be a need for improved methods of area-sampling to enable reliable comparisons to be made of the levels of air pollution to which the experimental populations are exposed.

MEDICAL STUDIES

THE DIFFICULTIES OF INTERNATIONAL COMPARISONS

The report of the Fifth Meeting of the WHO Expert Committee on Environmental Sanitation (1957), in addition to stressing the need for standardizing instruments, sampling and analytical methods, and the units used in measuring air pollution, also drew attention to the need for agreement on the terms used to designate associated disease entities such as chronic bronchitis and primary lung cancer. The need for such standardization is very evident. Although all European countries have medico-statistical services for the recording of mortality data, these are not always completely in accordance with the International Statistical Classification of Diseases, Injuries, and Causes of Death (World Health Organization, 1957). In many countries information is not available in a form suitable for epidemiological research. For the investigation of mortality associated with atmospheric pollution it is necessary to have a clear and precise classification of causes of death, subdivided according to age and sex, area and date of death. Information on social or occupational class is also useful.

No really satisfactory morbidity statistics appear to exist in any European country. In some countries information may be available from the records of official insurance schemes, from sickness certification, or from hospital admission data; but the indices derived from these sources have many imperfections. Information may also be obtained by the study of special sections of the community such as schoolchildren, the occupants of old people's homes, and hospital out-patients—especially those attending clinics for chest or heart disease. These, though useful for local or regional studies, are however of little value for purposes of international comparison. It is therefore of some importance to encourage states to give attention to the study of morbidity with a view to perfecting the use of satisfactory indices within their own territories as a step towards their international use.

DISEASE NOMENCLATURE: BRONCHITIS SURVEYS

No satisfactory international comparisons can be made until there is a greater mutual understanding on questions of disease nomenclature. A name given to a disease syndrome in one country is frequently applied to a somewhat different syndrome in other countries; false impressions of their relative incidence result. Considerable national differences also exist in the relative importance attached to the respiratory and cardiac components of the various cardio-respiratory diseases. In some countries doctors will tend to designate a cardio-respiratory condition by a name which implies a primarily cardiac lesion, while in others the same condition will be given a respiratory label.

Of the diseases most frequently linked with air pollution, bronchitis is notorious for its vague definition. Not only are there difficulties associated with the definition of the condition itself, but there is also the problem of deciding at what stage in the natural history of the disease it should be termed "chronic". Some clinicians hold that the chronic form of the disease already exists, for example, at its earliest stage in a child recovering from whooping cough. Others may regard it as having begun in a young or middle-aged man who has reached the stage of hypersecretion of mucus resulting in a chronic productive cough, even though the sputum is not yet purulent. Yet other authorities will only consider the condition chronic when the sputum has become purulent, or when the patient has experienced a series of exacerbations, or possibly only when the patient presents the full combination of chronic cough, purulent sputum, frequent winter exacerbations and definite dyspnoea. In established cases the nature of the condition will not be in dispute, but in some countries the earlier stages—so often associated with bronchial spasm—may be called asthma, and the later stages—where dyspnoea becomes a prominent symptom—may be called emphysema.

Because of these difficulties in nomenclature, bronchitis has been studied by the Medical Research Council of Great Britain and a detailed questionnaire for use in field studies has been compiled (Great Britain, 1960). With this method each patient is interviewed and questioned about his symptoms. Precise instructions are issued for the guidance of interviewing officers, who should be trained to ensure that a standard method of approach is used. The results, analysed statistically, provide a firm basis for comparative studies on the epidemiology of symptom complexes variously termed bronchitis.

The value of this questionnaire has been demonstrated in a comparative study of respiratory disease in England and Norway.¹ This

¹ Mork, T. (1960) *A comparative study of respiratory diseases in England & Wales and Norway* (unpublished working paper).

study was designed to determine (1) whether real national differences existed in the prevalence of respiratory symptoms and whether there were related differences in pulmonary function, and (2) whether any differences that might exist could be explained by variations in personal habits, environment, past history or anthropometric characteristics. In addition to the information derived from the questionnaire, measurements were made of peak respiratory flow, blood pressure, weight and sitting height, and morning specimens of sputum were also collected. The results demonstrated that real differences do exist in the incidence of serious respiratory symptoms in the two populations, differences which cannot be explained by occupational, social, economic or anthropometric factors. No differences were found in the prevalence of morning cough, occasional wheezing or history of previous chest disease; but an examination of smoking habits suggests that this factor may determine the prevalence of minor respiratory symptoms (cough and production of phlegm) independently of other environmental factors such as atmospheric pollution. The author of the study advances the hypothesis (which, he claims, is supported by other workers) that environmental factors, including atmospheric pollution, may be of great importance in the development of the smoker's syndrome with subsequent disabling, and often fatal, chronic respiratory disease.

It is evident that the Medical Research Council's questionnaire provides a valuable method of recording respiratory symptoms, capable of use in all countries and giving useful results irrespective of differences in nomenclature or in sources of mortality and morbidity statistics.

THE EFFECTS OF ATMOSPHERIC POLLUTION

The biological effects of atmospheric pollution may be studied in the laboratory or in the field, the two methods being largely complementary.

Laboratory studies have been carried out in many countries using the accepted methods of toxicological research. Like other toxicological studies, they suffer from the limitations inherent in the application of the results of animal research to man, and human experiments must be limited to observing the effects of safe dosages. Even greater difficulties are experienced in observing the effects of toxic substances on persons suffering from specific diseases. Even so, much useful work has been done on industrial emissions, often with the object of determining safe limits for workers engaged in factories and in ensuring the health of people living nearby. Problems of this kind are usually concerned with the effects of single chemical substances.

Greater difficulties are experienced in the laboratory investigation of the general pollution of the air of towns owing to the complex nature of the substances arising from domestic and industrial fuel consumption and of the waste products from the internal combustion engine and other industrial effluents. Despite the complexity of the problem, considerable progress is being made in the study of the products of combustion of coal, coke and fuel oils. This information will provide a useful background to the epidemiological studies now being pursued, which are essential if a proper assessment of the effects of atmospheric pollution is to be made.

EPIDEMIOLOGICAL STUDIES

Epidemiological studies may be designed to show the long-term effects of atmospheric pollution, the results of living in a polluted area for many years; the intermediate effects, those noted within weeks or months of experiencing some defined level of pollution; or the immediate effects, occurring within 24-48 hours of some increase in pollution. Studies may also be classified according to whether they are designed to show the mortal or morbid effects of pollution; and the latter may be further subdivided in relation to the whole population, a particular age-group, occupational or social class, or a group of patients suffering from a specific disease such as bronchitis.

DIFFICULTIES OF COMPARATIVE STUDIES

The use of epidemiological methods in the study of the effects of atmospheric pollution is fraught with many difficulties. In the past most information on pollution has taken the form of monthly averages, and so has directed epidemiological research towards the assessment of the long-term effects. This has resulted in the need for comparisons between the health of urban communities and that of control populations living in relatively unpolluted areas. Only recently, using the more extensive measurements of air pollution now being undertaken, has a start been made in assessing the immediate or short-term effects of pollution; and, as these studies permit assessment of the effects of varying degrees of pollution on the same population, controls are unnecessary.

The assessment of the effects of air pollution by comparing different communities subject to high and low degrees of pollution presents many difficulties, for the communities are certain to differ in many respects other than in the pollution of their air. Even when two towns of almost identical composition are compared, the fact that one is subject to a higher level of pollution implies that its inhabitants will

be of a different social and occupational class from those of the other. Environmental, climatic, anthropometric, social, nutritional and occupational factors may also be different. The smoking habits of the two communities will be particularly important, and among the environmental factors the types of domestic architecture and methods of house-heating must be considered. From this it is evident that comparative studies of two or more communities should be accompanied by very detailed investigations into the social and economic status of their respective populations.

INDICES OF MORTALITY

In all countries mortality is more accurately recorded than morbidity, and studies based on numbers of deaths provide a more direct method of approach than those based on morbidity. They cannot, however, give a complete picture of the situation since they take no account of the effects of atmospheric pollution in producing minor variations in health. Further, studies of mortality dealing with the immediate effects of atmospheric pollution can only be carried out in the largest populations. During the great London fog of December 1952, when a population of over eight millions was subjected to extremely high levels of pollution and the total additional number of deaths so caused was estimated at approximately 4000, the excess death rate per 100 000 population per day of fog was 12.2. Even in this great conurbation daily variations in the degree of air pollution have been shown to be associated with comparatively small variations in the numbers of deaths. It is apparent that in all except the largest centres of population the effects on mortality will be difficult to determine; and in small centres only the most serious episodes are likely to produce a significant rise in the number of deaths. Even in a city of half-a-million people the daily numbers of deaths in winter seldom amount to more than 40. Only rarely will incidents associated with an increased air pollution produce a statistically significant rise in the number of deaths, and under such circumstances a long series of observations would be needed to demonstrate any association between the two.

INDICES OF MORBIDITY

The study of sickness records might be expected to be more fruitful than investigations of mortality, since morbidity is a more sensitive index of deviation from normal health and well-being. Such studies should therefore show the effects of air pollution on the normal population, and not only on those already suffering from some severe disease.

Since cases of illness are more numerous than deaths, a morbidity index may be based on higher numbers and should therefore be less influenced by random variations.

Unfortunately, morbidity is more difficult to measure than mortality and suitable statistics exist in only a few countries. The data available are derived from:

1. *Absences from work.*

2. *Certificates given by doctors to enable patients to obtain benefits under insurance or social welfare schemes.* Here, however, the daily figures for public holidays or weekends are not comparable with those for working days; and even on working days the figures are very susceptible to social influences. Thus, sickness rates are found to diminish as Christmas draws near and to increase immediately afterwards. Certain days of the week are more popular than others for going off sick, and a pronounced weekly cycle may be seen. Some of these variations may be so consistent that it is possible to calculate appropriate correction factors. Again, absence from work and sickness certification relate only to the healthier age-groups of the community; the very young, the very old, and many of the chronic sick are excluded. Such data are therefore not a very sensitive measure of the health of the community.

3. *Hospital admissions.* In London the daily number of applications for admission to hospital has been found to provide a very useful index of morbidity from air pollution. From its nature this index can reflect only the more serious types of illness, since trivial cases are not usually admitted. In London the figures were found to have a pronounced weekly cycle, fewer applications being made at the weekend and a correspondingly higher number on Mondays; this source of variation can be eliminated by applying appropriate correction factors. As with the daily number of deaths, the figures are relatively small and this method is therefore only likely to be of use in dealing with large conurbations.

4. *Morbidity in children.* Many workers believe that measurements of morbidity in children provide a suitable index for assessing the effects of environmental conditions such as air pollution. Children constitute a relatively uniform group uninfluenced by the effects of occupation or tobacco addiction. Observations may be made with relative ease through the media of school or pre-school health services. For these reasons a number of studies have been made in children with the object of determining the pathological effects of air pollution. Some of these studies combined observations on general health with measurements of height and weight and with estimations of haemoglobin,

colour index, alkaline phosphatase, calcium, phosphorus and blood proteins (Faerber, Hoffmann & Schmitz, 1959; Trüb & Posch, 1959). These studies have mostly been concerned with the long-term effects of air pollution, thus necessitating comparisons between child populations in different areas. Their results must therefore be assessed in conjunction with evidence of the social, nutritional and economic status of the respective populations. However, considerable differences of opinion exist regarding the value of comparative studies of child populations. Children are generally a healthy section of the community. Any minority suffering from malnutrition, or from the effects of some previous disease such as measles or whooping cough, would be more susceptible to the ill effects of air pollution than the majority. It is therefore difficult to decide how far a given morbidity rate in a child population is due to air pollution, and how far it is due to some pre-existing level of disease or debility.

5. *Morbidity in the aged.* Because of their greater susceptibility to atmospheric pollution, populations of elderly people constitute a valuable field for studying its effects. The numbers are rarely sufficient to allow accurate epidemiological or statistical analysis, but observations of such groups as the occupants of old people's homes may provide much useful information.

6. *Military personnel.* Members of the armed forces form a group of healthy adults living under relatively uniform conditions of environment, occupation and nutrition. Their generally high standards of health may, however render the effects of air pollution very trivial.

7. *Studies on patients suffering from specific diseases.* The effects of air pollution are most evident in patients suffering from a lesion in the heart or lungs, and groups of patients suffering from such lesions provide a fruitful field of study. Thus, the Atmospheric Pollution Research Unit of the Medical Research Council of Great Britain has devised a method of demonstrating the effects of varying degrees of air pollution on patients suffering from chronic bronchitis (Lawther, 1958).¹ Patients attending London hospital clinics were asked to keep personal diaries in which each recorded his own assessment of his daily condition under one of four headings: "better than usual", "the same as usual", "worse than usual", or "much worse than usual". In a later study, these were altered to: "better", "same", or "worse", compared with the day before. From numerical translations of the diary entries it was possible to construct trend lines showing the day-

¹ Also: Lawther, P. J. (1960) *Some morbid effects of British air pollution* (unpublished working paper).

to-day condition of the group as a whole. Analysis of the results indicated that the patients were not influenced by their knowledge of the weather at the time. The results demonstrated this to be one of the most sensitive indices at present available. It is independent of any form of mortality or morbidity registration and is suitable for use in relatively small communities.

STATISTICAL METHODS

Epidemiological studies of air pollution depend primarily on the demonstration of an association between the index of pollution and an index of mortality or morbidity. In isolated incidents it may be sufficient to show that a rise in pollution coincides with a rise in mortality or morbidity rates, as in studies of the great London fog in 1952. Diagrammatic methods may be used in demonstrating this association over periods of time, as in the bronchitis diary studies already quoted. Where the daily number of deaths or sickness cases is small, the use of cumulative daily totals has been suggested. When the cumulative totals are plotted against a time-scale, a regular increment will result in a straight line if the slope depends on the increment, i.e., on the daily death rate. If the amount of the increment changes the slope changes. On such a slope the genesis of an epidemic will be indicated by a steepening of the curve. Any individual causes of mortality, such as a railway accident, will produce an upward step in the curve, which will then resume at the same inclination as previously. A mortality incident which has merely determined the moment of death of persons who were already at the point of death will be characterized by an upward step in the curve followed by a fall-off in its inclination until it resumes the track it would have taken had there been no such incident. The advantage of this method is that it may be used with small numbers, even with less than one death a day.

All these methods must, however, be used with a proper regard for the significance of the figures involved. In some studies the association may be so obvious that no assessment of significance is needed; in others an impressive graph may conceal a grave weakness in the significance of the numbers involved.

Most studies of the epidemiology of air pollution have been conducted using standard statistical techniques, such as the calculation of correlation coefficients, the results then being tested for significance. Long-term or delayed effects of air pollution are difficult to study on account of the many other factors that may influence mortality or morbidity over a period. Many workers have therefore used techniques such as partial correlation or multiple regression analysis in order to establish the

proportionate weight to be attached to these various factors. The possible use of discriminatory analysis has been similarly suggested for this purpose.

Almost all epidemiological studies of air pollution, whether based on the calculation of correlation coefficients or some similar statistical technique, or designed to demonstrate by some simple method an association between two or more indices, suffer from a common defect, viz., that the demonstration of such an association is not a proof of cause and effect. The findings must therefore be interpreted with care.

The increased use of daily records of air pollution has resulted in studies of its immediate and short-term effects and various statistical devices have been necessary to prepare the figures for correlation studies. Thus some observers, in studying short-term effects, have used three- or seven-day moving averages of mortality and morbidity figures with the object of reducing the effects of random daily variations. In mortality studies this method obscures the sudden rise that may occur immediately there is a marked rise in pollution, but, by tending to average out the peak with any subsequent compensatory period of low mortality, it may sometimes give a better indication of the true additional numbers of deaths than figures which may possibly include premature deaths of persons who would in any case have died in the course of a few days.

Before mortality or morbidity figures can be used for calculating correlation coefficients it is necessary to remove the effects of seasonal variations, or variations due to epidemics such as those of respiratory infections. For this purpose daily deviations from some smoothed-out curve, such as that produced by a 15-day moving average, have been used. As already indicated, some indices—for instance, those based on sickness certification or admission to a hospital—may exhibit a regular weekly cycle and this may be sufficiently consistent to enable adjustment factors to be calculated for each day of the week. Thus, the effect of the cycle may be eliminated.

SOME RESULTS OF EPIDEMIOLOGICAL STUDIES

IMMEDIATE EFFECTS OF HIGH POLLUTION

Apart from one or two isolated incidents elsewhere, only in the United Kingdom has it so far been possible to demonstrate the immediate effects of changes in air pollution. Daily values of the concentration of black suspended matter and sulfur dioxide have been correlated with indices of mortality and morbidity and have shown a much closer association than was previously suspected. The effects that are noticeable in patients suffering from cardiac or respiratory conditions may be observed within a few hours of a deterioration in atmospheric conditions, and are frequently evident even with quite small increases of pollution. The peaks in mortality are often followed by a corresponding fall, suggesting that the rise in air pollution may only have determined the time of death in patients who would otherwise have died during the next 24-48 hours. The effects of air pollution are noted only during the winter, and with the onset of spring this association with sickness and death disappears (Lawther, 1958; Martin & Bradley, 1960; Martin, 1961).

DELAYED EFFECTS

The delayed effects of air pollution are difficult to measure and have frequently been a matter of conjecture. Thus, after the London fog of 1952 it was suggested that much of the respiratory illness during the remainder of the winter, and even possibly in subsequent winters, might have been to some extent a consequence of this one episode. More recently an association has been demonstrated in London between the respiratory and cardiac mortality and air pollution levels attained some weeks previously.

In searching for long-term effects the influence of atmospheric pollution is more difficult to demonstrate, as for purposes of comparison it is necessary to use a control population in an unpolluted area. Studies of this nature have been carried out in a number of countries including Czechoslovakia, Germany and the United Kingdom. Investigations

in both Czechoslovakia ¹ and Germany (Faerber, Hoffmann & Schmitz, 1959; Trüb & Posch, 1959) ² have included comparative studies on the health of children in polluted and non-polluted areas, and differences in the incidence of disease and physical and nutritional differences have been observed. Much importance was attached to haematological examinations, and differences in haemoglobin, colour index, alkaline phosphatase, and calcium and phosphorus levels were found. In Germany signs of rickets were found in some children living in polluted areas. In the United Kingdom a study has been made of postmen who, whether living in a clear or a polluted area, were drawn from a relatively homogeneous social class and had similar occupational conditions. A higher incidence of bronchitis was noticed among postmen in areas where thick polluted fog was prevalent, and this morbidity could be ascribed with a considerable degree of certainty to atmospheric pollution (Fairbairn & Reid, 1958). Another British investigation has been concerned with the parts played by atmospheric pollution and cigarette smoking in the production of cancer of the lung (Stocks, 1952; 1959). In London the effects of social class, occupation, housing and population density were studied and the highest incidence of cancer of the lung was found in the north-east of the city where the prevailing winds brought air pollution from the centre and the south. Another study has been made on urban, rural and mixed communities in Wales and the north-west of England, where the environmental and social conditions of patients suffering from cancer of the lung have been compared with those of a carefully selected control series of patients suffering from other conditions (Stocks & Campbell, 1955). This investigation has led the authors to the conclusion that 3,4-benzpyrene and other polycyclic hydrocarbons play a dual role in the causation of cancer of the lung in virtue of their presence in both cigarette smoke and polluted air.

¹ Srdan, S. (1960) *Air pollution in Slovenia*; Symon, K. (1960) *Air pollution in Czechoslovakia* (unpublished working papers).

² Also: Heller, A. (1960) *Current air pollution problems and some recent studies on the effects of air pollution on health carried out in the Federal Republic of Germany* (unpublished working paper).

CONCLUSIONS

Air pollution is a most important environmental evil in Europe, causing much preventable sickness and premature death. In many of those areas of Continental Europe where measurements of sulfur dioxide and suspended matter have been made, the recorded levels of pollution by one or both of these agents have been comparable with those noted in the United Kingdom, where a relationship between these pollutants and respiratory disease has been demonstrated. It is therefore possible, or even probable, that the health of urban populations in many European countries is being adversely affected in a similar way. Further investigations are needed in all European countries to determine the nature and extent of the air pollution to which their populations are exposed, including the estimation—in addition to the pollutants commonly measured—of carbon monoxide, sulfuric acid, lead compounds, oxides of nitrogen, and benzpyrene.

Epidemiological studies provide the best means at present available for studying the influence of air pollution on health. In the planning and execution of such studies it is important that medical and chemical experts should co-operate so as to ensure that observations of pathological effects are matched by the fullest possible information on the air pollutants most closely related to those effects. Important results have been obtained in several European countries from recent epidemiological experiments. New techniques based on observation of the effects of day-to-day changes in air pollution on the population of a single area are of special interest because they avoid the difficulty of working with two populations which must be identical in every respect except the degree of pollution to which they are exposed. Convincing evidence of the effects of specific air pollutants may be obtainable from internationally co-ordinated investigations carried out under varying climatic and environmental conditions.

The results of epidemiological research may have important applications in the control of noxious pollutants. The observed diurnal

relationship between disease and such indices of pollution as the sulfur dioxide content of the atmosphere or the concentration of suspended matter suggests the possibility of defining a minimum standard of air purity. This limit might be that concentration of an agreed pollutant below which changes in morbidity and mortality are not demonstrably related to changes in the concentration of the pollutant.

Not all types of air pollution measurement are equally suitable for epidemiological purposes. Measurements of dustfall, or of sulfur dioxide using the lead dioxide and similar empirical methods, are unlikely to give useful results and are not recommended. On the other hand, measurements of sulfur dioxide by the hydrogen peroxide method, and of suspended solids by gravimetric and other quantitative methods, have proved their value. The composition of suspended matter varies greatly from place to place according to the nature of its source and other factors, and further research is needed on the differing physical and chemical properties of these materials and their different pathological effects. Two methods are currently in use for measuring the suspended matter in the air. A gravimetric determination of the "total suspended matter" is preferred by some authorities; and a photoelectric assessment of the "black suspended matter" (smoke) is also widely used, the latter being affected by the degree of darkness of the suspended pollutants. Two important considerations are the absolute quality of the gravimetric method and the fact that daily reflectivity measurements have already found a useful place in epidemiological studies. Correction factors are needed to provide comparability between areas which differ in the characteristics of their air pollutants. The study of these two methods is continuing.

Variety in instrumentation and methodology is important. Continuous recorders and sequential samplers are useful in studying peak concentrations; but, for most epidemiological investigations, simpler apparatus providing average results spread over somewhat longer periods, such as 24 hours, are likely to be more generally useful. There is a need for standardizing instruments, units of measurement, sampling and analytical methods, and terminology. Steps to this end are being taken in Western Europe by the Organization for Economic Co-operation and Development, by some countries of Eastern Europe, by other national agencies and organizations, and on a world basis by the World Health Organization. Generally accepted methods suitable for the specific needs of epidemiological research are required. The standardization of medical terminology is an essential prerequisite for much of the epidemiological research on air pollution since diagnostic criteria used by doctors may differ. At present there are important variations between countries which invalidate most international comparisons.

The experience already gained in comparative studies of bronchitis by means of the questionnaire of the Medical Research Council in the United Kingdom should form a useful starting point. Laboratory and field studies are to a large extent complementary, information provided by the laboratory being confirmed by field observations and vice versa.

Much of the success of epidemiological studies depends on the quality of medical statistics available. Mortality statistics, though collected in every country, vary in quality and provide information significant for air pollution research only in respect of the larger conurbations. Morbidity indices should be more sensitive to the effects of air pollution but no really satisfactory figures were found to exist in any of the countries represented at this Symposium. Greater attention should therefore be given to the study of morbidity with a view to establishing indices that will prove more suitable for use in international comparative studies. In the absence of comprehensive morbidity indices, sources such as data obtained from insurance schemes or hospital admission records, and from special population groups such as schoolchildren or the patients of hospital clinics for chest diseases are capable of providing useful information on a local or regional basis.

The effects of air pollution may be conveniently considered under three headings :—

- (a) The immediate effects, those occurring within 24-48 hours of the onset of serious air pollution.
- (b) The intermediate effects, those occurring within several weeks or months of heavy pollution.
- (c) The chronic or long-term effects resulting from prolonged exposure over many years.

Studies of the immediate effects of air pollution may be undertaken when satisfactory daily values of air pollution and adequate mortality or morbidity data are available. As with all correlation studies, the results have to be interpreted with care, and it has not usually been possible to determine which of the constituents of a polluted atmosphere are responsible for the effects observed. Studies of the intermediate and chronic effects are more difficult to pursue. They usually depend on comparative studies made on populations in polluted and non-polluted areas. The greatest care must be taken in interpreting the results of such comparisons, as a wide variety of social, economic and other factors can create differences between two populations that may invalidate the results.

Great advances are now being made in the field of mathematical statistics and, as more basic data become available, opportunities will

present themselves for the use of more refined methods of analysis. The best advice obtainable from universities, research establishments, and other bodies with experience in this field should be utilized. It is important to foster better facilities for communication and exchange of information between physicians, epidemiologists, chemists, physicists, sanitary engineers, statisticians, meteorologists, administrators and others working in the field of air pollution; team work is essential. There is also a need for improving training facilities on an international basis.

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