International Symposium on

Identification and Measurement of Environmental Pollutants

Ottawa, Ontario, Canada
14, 15, 16, 17 June 1971

in association with

the Association of Official Analytical Chemists,
the International Union of
Pure and Applied Chemistry,
the Chemical Institute of Canada,
the Agricultural Institute of Canada and
the National Research Council of Canada

Symposium international

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FOREWORD

The theme for the Symposium in Ottawa was selected in response to deepening concern over environmentally-related problems and in conformity with the primary objective of the Association of Official Analytical Chemists " . . . to secure, devise, test and adopt uniform, precise and accurate methods of analysis and to give official sanction to those found acceptable". Further, it was hoped that the interchange among scientists working in diverse areas of environmental pollution would result in the cross-fertilization of ideas and the adoption of better techniques and procedures for identification and measurement of pollutants.

The actual implementation of the Symposium was made possible through the initial interest and encouragement of Officials of the Research Branch, Canada Department of Agriculture, and with the financial support of the National Research Council of Canada. Committees which were responsible for planning and arrangements, as well as organizations and agencies which sponsored and provided added support, are listed in the section on Acknowledgements. To all of these and to the personnel of the National Arts Centre, I express my sincere appreciation for their support and hard work which culminated in a highly successful Symposium.

The pages that follow attest to the scientific stature and outstanding ability of the invited Symposium speakers and plenary lecturers. The ultimate value of the Symposium rests on their individual contributions. Members of the Symposium audience contributed immeasurably to the Symposium as well by recording their questions and views.

Finally, on behalf of all who participated in the Symposium, I express deep appreciation to His Excellency, The Right Honourable Roland Michener, C.C., C.D., Governor General of Canada, for taking part in the Opening Ceremonies and for his interest and concern over the subject matter of the Symposium.

I. Hoffman,
Symposium Chairman.

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PLENARY SPEAKER

The Need for Environmental Monitoring*

M. W. HOLDGATE
UNITED KINGDOM

This symposium is about the detection and measurement of environmental pollutants. Surely there are two questions that such a title immediately evokes, both so basic as to sound almost silly when one enunciates them. The first is 'what is a pollutant?', and the second 'what is one trying to detect and measure it for?'

THE NATURE OF POLLUTION

We call something a pollutant when human activities elevate its concentration in the environment to the point at which it begins to have effects we do not welcome. A pollutant is most usefully defined as something that is present in the wrong place, at the wrong time, in the wrong quantity.

There are three important generalizations enshrined in this definition. First, virtually any substance that is capable of influencing the living systems of individual animals or plants, of modifying the balance of species in ecological systems, or of affecting the physical and chemical processes of the biosphere, can be a pollutant. Secondly, it is the nature and size of the effect of a pollutant that matters, not its chemical structure or inherent scientific interest. Thirdly, and most important of all, our appraisal of the significance of such effects and the priority we give to control of a particular pollutant is a matter of social judgement. At the outset of a symposium that will be devoted largely to scientific techniques for the detection and measurement of such substances, we do well to remind ourselves of these wider issues, for these determine whether the measurement and detection to which we devote such effort and ingenuity is necessary.

OBJECTIVES OF ENVIRONMENTAL MONITORING

It is not surprising that our objectives in detecting and measuring environmental pollutants likewise include both scientific and social components, closely interwoven though they be. I suggest these objectives are:

1) to assess the present pattern of distribution of environmental pollutants in space, and so identify the areas where concentrations are highest and problems potentially most severe;

2) to determine the temporal trends in the concentration and distribution of pollutants, and so discover whether a situation is improving or deteriorating, and with what rapidity, and to relate such trends to sources and pathways of the materials in question;

3) to monitor the effectiveness of measures that Governments or others may take to combat pollution of the environment, usually because of the need to protect man or natural resources;

4) to enhance understanding of the processes whereby pollutants act upon physical and biological systems and so to improve both assessments of the magnitude of the problems they present, and prediction of the options and needs for pollution control and environmental management in the future.

There is a good deal of ambiguity in the use of terms to describe such activities, and for the remainder of this paper I shall use 'survey' to describe the first type of operation, 'surveillance' to define the second, and 'monitoring' only to refer to the third in which trends and levels are examined in relation to a standard and as a part of a regulatory machinery.

Survey, surveillance, and monitoring all demand the quantitative measurement of pollutant levels in the environment as a basis for relatively immediate action by Governments and other responsible agencies. These three activities to some degree stand apart from the measurement of pollutants and other environmental variables in order to enhance our knowledge of the natural processes of the earth and its living systems, and the effects of pollutants upon them. Yet it is obvious that there must be a feedback from one to the other. The very

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*The views expressed in this paper are those of the author and do not define the policy of his Department.

decision as to what is worth surveying or monitoring must depend on an assessment of the likely seriousness of the problem, and this in turn depends upon an assessment of effect. The social importance of maintaining a healthy and satisfying environment, and the economic cost of pollution control in a technologically advanced society are so great that even a minor improvement in our understanding of the true effects of a pollutant can bring great benefits or great economies. For it is important not to underestimate the scale of this business. It has been said that an industrialised country must expect to spend 10 per cent of its gross national product on environmental management. This statistic probably means little, for much depends on what one classifies as environmental management, but it may be a significant pointer that even in a small country like the United Kingdom it was estimated that between 1958 and 1968 the major industries spent £480 million on abatement of emissions to air (Chief Alkali Inspector, 1968), that expenditure on new sewage treatment works has been fixed at £700 million over the next 5 years, and that the cost of new sewage works to eliminate gross pollution in any one of three or four major British estuaries works out at around £15 million to £30 million apiece. Even so, we rely on the sea to take in, dilute and recycle a large part of the world's wastes. How much will it cost if we are no longer able to count on this "free" service?

THE NEED FOR "BACKGROUND" KNOWLEDGE

Any ecologist or biogeographer must recognize three general characteristics of ecological systems: first, that they are adapted; secondly, that they are in a state of continual change, and thirdly that there is a relationship between their diversity and their stability. The first and second characteristics are well illustrated when you consider the history of Canadian or northern European vegetation and fauna over the past 20,000 years, for on this time span tundra communities, conifer forests and broad leaved forests, each a mesh of individual organisms of individual species adapted to particular conditions, have flowed northwards in successive, intermingled waves in the wake of the retreating ice, moving with the belts of climate and readjusting because of the maturation of the raw soils and the evolution of the ice-moulded and drift-impeded drainage systems. The third characteristic is well seen in nature if you compare a tropical rain-forest with the grasslands of an oceanic island. The former may contain as many as 300 canopy trees (Poore, 1968) and great diversity of epiphytic and ground vegetation. If any selective disease or outbreak of a herbivorous insect were to eliminate one component tree, there are many competitors that can move in and take its place without a significant alteration in the aspect of the whole. Likewise, it is buffered against climatic change by the longevity of the dominant species, and creates its own internal microclimate, thus further shielding the smaller species against the vagaries of the environment. In contrast, there are tussock grasslands on the coastal slopes of southern oceanic islands with no alternative dominants if some pressure such as the introduction of a grazing mammal eliminates the original main species; coastal erosion and the breakdown of the system ensue (Holdgate, 1967).

Man is a simplifier of ecosystems. The grasslands he has sown, the crops he grows, the forests he manages have fewer species and less inherent stability than the natural vegetation they have superseded. Moreover, man's impact is no more constant than any other environmental variable. Systems of husbandry and degrees of intensity of land use change. The modified systems of the earth – and over most peopled lands there are few areas not to some degree altered by man – exhibit a huge variety of change in response to natural and human pressures.

The point of all this is that it makes the effects of pollution on ecological systems extremely hard to interpret. There is a serious danger that quite spurious interpretations will be put upon observations that correlate in time but may have no causal relationship. Lamb (1970) and Weiss and Lamb (1970) have pointed out this dilemma clearly in the climatic field. It is well known that the mean temperature in north-west Europe was higher, and there was a high prevalence of westerly winds, in the first half of the twentieth century, but that in the last decade there has been a cooling and a change in the prevailing wind pattern. It has been suggested by several authors (reviewed in SCEP, 1970) that the initial warming resulted from the 'greenhouse effect' of the carbon dioxide released into the air by the burning of fossil fuels, and there is no doubt that the CO_2 content of the atmosphere has moved steadily upwards from about 290 ppm in 1890 to 320 ppm in 1969 (Council on Environmental Quality, 1970). Conversely, the more recent cooling might be attributed to the effects of fine dust in the upper air, screening out incoming solar radiation. The ejection of dust in great volcanic eruptions certainly appears to be associated with cool summers in the northern hemisphere (Lamb, 1970). But as Weiss and Lamb (1970) point out, the changes in temperature this century fall fairly exactly on a curve of climatic oscillation with a period of some 200 years, which can be traced back in the chronicles and through a variety of circumstantial evidence for some 7,000 years. The correlation with pollutant changes (and the evidence for a significant change in dust levels since 1960 is far from good) may well be completely coincidental.

If one is to avoid pitfalls of this kind, and so avoid serious errors in our assessment of the gravity of a pollutant problem – and hence the misuse of resources for pollution control – we have to know the natural background situation. Just as we cannot appraise the significance of the effects of a pollutant or toxin on man without a basis of physiological and biochemical understanding of the healthy body, so we cannot appraise the impact of a pollutant without some comprehension of the responses of the natural world. Ecosystems are complex, and such knowledge cannot be gained by a few months study. The basic knowledge must be gathered over several annual cycles, during which a great variety of physical and biological variables are measured. Such variables will include pollutants. The study of comparable ecosystems under varying conditions, including varying levels of pollution (the ecological equivalent of an epidemiological survey), will help to point to likely real causal relationships, some of which are likely to be brought out by sophisticated techniques of statistical analysis.

THE PROPERTIES OF POLLUTANTS

Against such a background one can review the intrinsic properties of pollutants themselves. Almost any chemical substance can be a pollutant. This does not mean that all pollutants are equally severe in their effects. In some cases, as with gases such as carbon dioxide or sulphur dioxide, both of which are natural components of the earth's atmosphere, or phosphate and nitrate which are essential nutrients in fresh water, serious problems are created only when concentrations are very high and ecological imbalance is threatened. Other substances have more dramatic effects at much smaller concentrations. It is possibly valid as a generalization to suggest that when assessing the potential hazard posed by a pollutant, one should pay attention to the following properties:

1) 'Naturalness'.
2) Toxicity.
3) Dispersion.
4) Persistence.
5) Reactivity.
6) Biodegradability.
7) Bioaccumulation.
8) Capacity for control.

The importance of some of these attributes is obvious: the inverse relationship between the potential nuisance of a substance and the availability of technology to control it being the most self-evident. Others are less trite than they may seem at first sight. Clearly the toxicity of a substance in turn determines the maximal concentration which one can allow it to attain in the environment if one is not prepared to accept adverse effects. But in this context the concept is clearer than the means of measurement, and one question to which we might address ourselves in this symposium is: are our methods for appraising toxicity adequate? Often we rely on measurement of the level that kills 50 per cent of a sample of some test organism in a relatively short time. Is this a reasonable index of chronic effects over very long exposures? What constitutes a "typical" test organism? Should one vary one's test organism with locality (Tarzwell, 1971) – or will this make the experiment useless because of loss of comparability? What of behavioural effects not manifest in the laboratory? Work in Canada (Anderson, 1971) has shown that concentrations of DDT as low as 40 parts per billion (10^9) may affect the cold- resistance of young salmon and trout to an extent that could affect the survival of whole populations in winter, yet such insidious effects are unlikely to be brought out by conventional toxicity testing. Bryan (1971) has described a wide range of lethal and sub-lethal effects of metals on marine organisms, some of them beginning at concentrations only an order of magnitude greater than the natural background, and has shown how complex the variations with species and circumstance are. There is room for much study here.

Persistence, likewise, is clearly relevant for it determines how long a pollutant remains unchanged in the environment and hence affects the concentrations that will be attained. Dispersion is a third physical parameter relevant to the calculation; by it I mean the rate of diffusion, solubility or mobility of a material that governs, for example, whether it spreads freely through a water body or deposits as an inert sediment. Biodegradability and chemical reactivity are aspects of persistence, but important properties; for some materials at least the former can be predicted from chemical structure (Iliff, 1971) and hence put in rigorous scientific terms. Bioaccumulation is well known as an inconvenient property shown by some of the most troublesome of environmental contaminants such as heavy metals and chlorinated organic substances, which living organisms concentrate many times in their tissues, often passing the accumulated burdens from prey to predator along a food chain so that a material widely dispersed at low concentrations in sea, freshwater or soil comes to exert significant physiological effects on a predator such as a seabird, a hawk, a seal, or a man at the end of the sequence. Effects of this kind are very well documented and largely account for the problems encountered with mercury in fish (e.g. Löfroth, 1969: Ackefors, 1971), polychlorinated biphenyls in seabirds (Koeman *et al.*, 1969; Prestt *et al.*, 1970; Holdgate, 1971), or seals (Bonner, 1970) and organochlorine pesticides in a variety of organisms (Dustman and Stickel, 1969; Stickel, 1968). Many of these materials are fat soluble and accumulate in depot fat and in the liver. However, we are far from knowing in detail the processes governing the rates of accumulation in various organisms and under varying conditions. The concept of 'naturalness' stands aside from these intrinsic properties, and yet should likewise be assessed, for it can reinforce the others. Some pollutants have been present in the environment throughout evolutionary history, and only pose problems because man has greatly raised their levels. In addition to CO_2, SO_2, nitrates and phosphates, all very abundant, this category includes fluoride (fluorine is said to be the thirteenth most abundant element in the earth's crust), lead, mercury, cadmium, chromium, zinc, copper, and many other elements. Generally speaking, with such substances the first essential is to appraise how far human activity is raising their concentrations generally or locally above the natural background, which it is important to determine (and about which far too little is generally known). Conversely, other materials now being shed into the environment have been synthesised by man within recent years and organisms have not hitherto been exposed to them. There is a possibility that their biochemical systems will prove unduly sensitive to them, and such 'unnatural' materials (such as organochlorine pesticides) need especially careful scrutiny.

It should be possible to quantify these properties and combine them in a formula to give an index of potential hazard for a particular substance. In practice, such a procedure would almost certainly tell us what is obvious already: that materials of high toxicity, high persistence, low biodegradability, readily accumulated in living tissues, and not naturally present in significant quantities in the biosphere, such as heavy metals and chlorinated, fat-soluble, organic compounds, are the most trying of environmental contaminants. It is not surprising that such materials are listed in particular by international expert groups as posing the highest hazards (e.g. GESAMP, 1971).

Such an analysis can give us pointers to the likely nuisance a substance may pose. But in the end, the most important thing is the nature of the effect created and the degree to which it is socially acceptable.

THE EFFECT OF POLLUTANTS

Traditionally, and probably rightly (although it is a matter of social judgement rather than strict logic), we look on pollutants that can be shown to have an acute effect on human health as the most serious. It was the death, as a result of the great smog of December 1952, of some 3,000 to 4,000 more people in London than would normally have died in that period, that provided the main impetus to smoke control, provided under the first British Clean Air Act in 1956 (Royal College of Physicians, 1970). The recognition of mercury as a serious environmental pollutant was made inescapable by the deaths of some 43 people, and irreversible brain damage to about 60 more, at Minamata Bay in Japan between 1953 and 1960. Yet despite the emphasis we place upon it we are still sadly ignorant about the effects of many pollutants on man, especially when the exposure is (as it generally is) to low concentrations in food, water or the general environment over long periods. It is one thing to say, as we can with some certainty from clinical studies, that symptoms of poisoning can appear when levels of lead in the blood exceed 80 μ g/100 ml (Kehoe, 1969) or that people who eat 200 grams of fish containing an average of 10 parts per million of mercury every day will be likely to suffer evident damage (Löfroth, 1969). It is quite another to be sure that the biochemical changes that are detectable in blood at levels right down to the "normal" values around 15-20 μ g/100 ml of lead (Hernberg and Nikkanen, 1970; Malcolm, 1970) are of no long-term significance, or to relate the curve of biochemical effect to pollutant levels so precisely that one can determine the threshold at which a particular pollutant will be likely to have a recognized deleterious effect. Yet, unless one has such a curve, can specify such a threshold, or set realistic safety factors, what meaning can one assign to the measurements in the environment of the pollutants the analytical chemist is becoming increasingly skilful at detecting? Pending such precise scientific evidence, what safety factor should one allow? For mercury in fish, several Governments have set arbitrary standards around one tenth to one twentieth of the mean figure associated with acute poisoning at Minamata. Is this too cautious (in which case a valuable food resource is being wasted) or too lax (in which case people may still be at risk)? Most people would agree, intuitively, that Governments must err on the side of caution, but how far? In the United States, there are legal restrictions on the addition to foodstuffs or use around the home in pesticide preparations of substances which can be shown to be carcinogenic or teratogenic. The principle is obviously sensible, but how many substances will not be liable to upset the delicate mechanism of the animal body at some concentration or other, or when injected into it in massive doses? Should one specify that the test should always be comparable to the real situation, that contaminants of food and water should be administered orally and gaseous pollutants by inhalation? Should one specify that effects only obtained at concentrations one hundred fold or one thousand fold of those likely in real life should be ignored? What margin does one allow?

Similar questions arise when one considers what is generally considered the next most serious category of effect of a pollutant: acute or chronic damage to domestic livestock, to wild species such as fish on which we depend for food, to crop plants, or to other species we value as a resource or amenity. The curves relating concentration and effect are non-linear, ill-defined, and often known only at a few points. One knows, for example, the threshold for gross visible damage to certain plants by sulphur oxides; this curve has been used to assess the effectiveness of the policy of dispersion of gases from power stations in Britain through tall chimneys (Ross, 1971 and in press), while it has been shown that the mean concentration of sulphur dioxide over lowland Britain can be mapped using the lichens growing on tree trunks as indicators (Hawksworth and Rose, 1970). But one does not know the "sub-clinical" pattern of the relationship. We may be fairly confident that the very low concentrations of DDT and other organochlorine pesticides detected as a result of improvements in analytical technique in the body fat of penguins in two parts of the Antarctic are of no biological significance, but we do not know the threshold above which it would be highly dangerous to allow organochlorine levels in the sea to rise (Butler, 1971).

The individual organism is a microcosm of the ecosystem, and on both, pollutants act as factors causing subtle adjustments of a continually shifting dynamic equilibrium. The kinds of dilemma I have just stressed apply with equal validity, therefore, to ecosystems as a whole, or indeed to the effects of pollution on the physical and chemical systems of air and ocean, or to the corrosion and damage to man-made structures. But it would be labouring the point to develop it further.

THE SELECTION OF THINGS TO MEASURE

It is relatively easy to sit in an armchair and think up comprehensive schemes for the measurement of the almost innumerable variables that influence and compose natural systems. Various expert groups and committees, at both national and international levels, have done just this, with widely varying degrees of success. I do not wish unduly to disparage their work, but the fact remains that, in the real world, resources of men and money, social priorities for their deployment, and the limitations of analytical methods and instruments, make it doubtful how far such schemes are useful, other than as classifications from which the most important and urgent problems can be selected. Such classifications are needed as a starting point, for without a fairly comprehensive schema of the systems and parameters that might be studied it is impossible to place the actual programmes that one undertakes in proper context. But in my judgement, they are no more than a vital first step.

Science advances through the making of significant abstractions and generalizations, through the making of conceptual models that allow prediction and the testing of prediction against observation and experiment. This remains a valid statement in ecology and in the study of pollution. What we need, in deploying our limited resources for the study of the natural systems of the world and the surveillance and monitoring of man's impact upon them, is a high efficiency of selection, abstraction, and modelling. For it is obvious that to measure and record all the multifarious variables we could measure, were it feasible (which it is not), would give us a body of data as complex and extensive as the real world. What is needed is a much more restricted series of measurements that are indicators of the state of the real world, allow prediction of its trends, and allow our social, economic and administrative policies to be adjusted so that we attain a better balance between man and environment.

To this end we must do three things: first, we must choose from our comprehensive classification of potential studies those that have highest priority; secondly, we must ensure that we have adequate scientific method to investigate them and attain meaningful results, and thirdly, we must ensure that having obtained the data we are able to interpret them properly and formulate accurate predictions – or at least, predictions whose accuracy is known. I propose to examine some of the many issues that arise in these three steps.

THE ASSESSMENT OF PRIORITIES

There are four kinds of criteria that usually govern the actual choice of a programme of measurement of a pollutant:

1) The intrinsic importance of the pollutant (or rather, of the problems it poses). The properties of the pollutant itself form one element under this heading; another is composed of the nature of its effects, and the third is the sheer scale of the problem. Taking this last first (for it is too trite to linger over), it is obvious that, however fascinating the action of a rare pollutant on a minor biochemical process may be, when it comes to investing research effort at Governmental level it will rate only a minor apportionment of resources compared with some large-scale, or even world-wide problem such as the dispersal and effects of sulphur dioxide, organomercury compounds, or new synthetic potential carcinogens.

2) The urgency of the problem. Where there is reason to suppose that concentrations of a pollutant in the environment fall far below the threshold at which effects are likely on anything more than a local scale, and where, moreover, levels can be expected to fall in the future (for example, because of changes in fuel policies), clearly there is less case for a major input of effort to survey and monitor than when the safety margin appears narrow and the problem a mounting one (as has been alleged for nitrate in some water supplies, or lead in some urban atmospheres).

3) The availability of analytical methods that allow meaningful measurements in the first place. Until these have been developed and proven there is no point in wasting effort in attempting to measure the unmeasurable. In this context, let us recall that it is only recently that the measurement of polychlorinated biphenyls and organomercury compounds in the general environment has become feasible. There are many substances for which it is clear that resources should be devoted to the development of techniques for better assessment rather than to premature and inadequate surveys of levels in the environment. A particularly good example here comes from the fresh water field, where we still need much new development if we are to measure on a routine, automated basis, using relatively unskilled labour, many trace contaminants that may yet pose important problems where re-use of water is contemplated.

At this point I would like to comment briefly on what is commonly termed 'biological monitoring'. The term is sometimes used ambiguously, for there are two aspects to it. On the one hand, it can be used to describe the measurement of pollutant residues in living organisms. This is done as a routine for many foodstuffs, and is also useful because, since organisms accumulate some materials in their bodies to levels well above those in the environment, and do so over time, tissue analysis can give an integrated figure for the pollutant level in an area over a period and can provide the chemist with materials at concentrations that are easier to determine than in the great dilutions in which they occur in the environment. Such measurements have proved their value as indicators of environmental contamination with pesticides, polychlorinated biphenyls, and various metals, and will obviously continue to be important. In contrast, 'biological monitoring' is also used to describe methods whereby the absolute and relative abundance of species in plant and animal communities is used as an indicator of the overall state of the environment; this can be done for a river (e.g. the "biological index" developed for the River Trent in England by the River Authority), for air (Hawksworth & Rose, 1970), or for areas of sea (Tarzwell, 1971). Variations in growth and performance of individual species (for example, the seaweed *Laminaria* described by Burrows, 1971a, 1971b) can also be a useful indicator of pollution levels. Such techniques will, undoubtedly, continue to be developed, but I believe that great care is needed with them, for the variations in abundance of species in an ecosystem depends on the balance of many factors, natural and artificial, and ecosystems show natural changes of a cyclical nature. All these must be understood if observed change is to be interpreted rightly, and there is a serious danger of spurious correlations. Even variations in the vigour, growth rate, or appearance of a single species can have many causes and it is doubtful whether observations of performance will ever serve as a technique on their own, unsupported by physical and chemical measurement. More likely, observations of species performance and abundance will be used as a first step, from which hypotheses may be framed that can be investigated by other analytical techniques.

4) The value of the parameter or factor we choose to measure as an indicator of the wider situation. For example, if the surveillance, at six-monthly intervals, of the composition and dimensions of lichen communities on tree trunks gives a good integrated assay of sulphur dioxide and photochemical oxidant levels in a region, this may be more useful and economic as a technique than the more frequent chemical measurement of the various gases. Likewise, the capacity of mosses to accumulate metals and other components of particulate 'fall-out' from the air may make their periodic sampling a more useful general guide (if we want a long-term guide rather than details of short-term fluctuations) than more frequent individual sampling (Goodman and Roberts, 1971).

METHODS, FIGURES AND MODELS

One of the surprising things about the statements that are made about environmental pollutants and their levels in the environment is the rarity with which standard deviations are cited, or with which the method used to arrive at a figure is made clear. In evaluating levels of PCBs in seabirds that died in the Irish Sea in 1969, for example, an important factor was that the method of analyses employed was still relatively inaccurate, particularly once the higher levels of PCB were reached, when an order of accuracy to the nearest 10 or even 100 ppm had to be applied (Prestt, Jefferies and Moore, 1970). One thing I hope this Symposium will emphasize is the essential requirement in this as in other fields of science, for the limits of accuracy to be attached clearly to figures on which so much effort and expenditure may hang.

Moreover, the inter-comparability of results obtained by different laboratories and different methods is something to which many of us pay lip-service, but which has more rarely been examined by actual interchange of specimens. One group, working under OECD, has done just this for organochlorine residues in birds and marine organisms and found that, while there are differences between the ability of analysts in different countries to detect and estimate pesticide levels, these are small in comparison with the variation between animals in a natural population. The agreement is good enough for a collaborative monitoring programme to be feasible (Holden, 1970).

There are two points I would like to put forward here, for others to develop in later sessions. First, what we really want is that results obtained in different laboratories should have comparable reliability, and secondly, that they should be measurements of the same thing; if this can be guaranteed uniformity of technique is unimportant. (The study reported by Holden involved many different methods.) If, however, different techniques measure subtly different things because of different sensitivity to different compounds within a broad range (such as may be grouped together when total mercury, total lead, or PCB are measured), then it is vital to ensure intercalibration if not standardization when data are to be fed into a regional or global system of appraisal.

The data must be useful in prediction, for we are concerned with planning and guiding the future, not just analysing the past. Because of the vastness of the data even now gathered on pollutant levels in many parts of the world, we must rely on the capacity of modern computers to collate and store the information, and we must look to mathematical models for such prediction. Such models are already familiar so far as atmospheric processes are concerned, in the field of climatic forecasting, and in predicting the dispersal of a pollutant in air (Murgatroyd, 1969) or estuaries. There is more controversy over their application to complex ecological systems, because the basic processes of interaction of individual animals and plants are less understood and less reducible to mathematical form (cf. Van Dyne, 1966). But the models developed in the International Biological Programme (e.g.Heal, 1970) are a pointer to what may be done, and I believe that such models will be developed and will at least soon reach the point at which, given basic knowledge about the threshold of effects of various pollutants on organisms, useful prediction of the likely pattern of hazard to living resources can be built into the models describing dispersal and dilution of pollutants. The pattern of response of ecosystems to pollution and many other kinds of disturbance is sufficiently similar and predictable to offer some hope of this. (Woodwell, 1970).

SOCIAL JUDGEMENTS

How acceptable are effects such as these? What criteria govern social acceptability? As scientists working on pollution, or as administrators serving Governments, or as Ministers influencing national or international policy we cannot evade an attempt at answering questions of this kind. At the outset let us recognize that there is no single world standard of acceptability. A people that are badly fed, lacking in fuel, and living in squalor are bound to be less fastidious in their environmental tastes than a more affluent community. If the expectation of life in a population is but 40 years, chronic pollution that begins to have damaging effects after 55 years may be regarded as acceptable. It would not be so in a community where executives reach the peak of their authority at this later age. A grossly polluted stream winding through suburban housing in a European or North American city is now socially unacceptable; the same stream might well be welcomed in a deprived community if it means that new industry is bringing vital employment. So much is it a matter of relative social values that it is dangerous to make international generalizations; rather, each community is best left to assess its social priorities in keeping with its own stage of development. Conservation, in this sense, may well be a preoccupation of the 'middle class state' no longer forced to devote every ounce of disposable economic growth to basic priorities of food, shelter, warmth, and medicine.

But within even a sophisticated society real dilemmas of choice exist. Should one set one's standards of environmental protection to shield the member of the community who is most at risk? This is done, for example, for the discharges of liquid radioactive waste from the treatment plant at Windscale in Cumberland, where the aim is to keep the level of the isotope of ruthenium ^{106}Ru below the point at which harm might be caused to the most addicted of a small group of people in South Wales who eat large quantities of 'laver bread' made from a seaweed, Porphyra, which accumulates this substance (Woodhead, 1971). It may be argued that on any economic basis such an approach is wholly ridiculous, for it would certainly be cheaper to compensate the consumers of seaweed and maintain less expensive waste disposal and monitoring procedures. Even more extreme questions arise where the safety of wildlife is concerned. It may well be that the organisms most at risk from marine pollution are seabirds and seals, coming at the end of food chains and particularly at risk from floating oil. Levels of contaminant in fish, that would cause no anxiety so far as human consumption is concerned, might be none the less liable to cause harm to other species that are exclusive fish eaters. Does one control pollution, maybe at considerable cost, to protect seals and guillemots?

Granted a first concern to protect human health and subsidiary, but none the less important, desires to preserve natural resources and amenity, the precise quantification of just how much of a particular pollutant can be tolerated in a particular section of the environment must be governed by three sets of criteria:

a) proper understanding of the relationship between concentration and effect;

b) assessment of the particular characteristics of the area of environment in question;

c) the nature of the analytical methods and control mechanisms available.

The less certainty there is about the relationship between concentration and effect, the wider the safety margin it will be necessary to allow. Similarly, the assimilative capacity of the environment cannot properly be judged without detailed knowledge about intrinsic properties of the pollutant, ecological characteristics of the environment, and the relation between them. Finally, the sheer limitations of technique may make it necessary to allow wider margins than would be desirable in theory. Taken together, however, these considerations must lead to the establishment of some kind of standard. What it is must depend on detailed circumstance.

In strict logic, the standard should always be based on the desire not to permit a particular pollutant to attain a concentration at which unacceptable effects begin. The assessment of the assimilative capacity of the environment and the threshold of physiological and biochemical damage to the organism is thus the first step. It follows that no uniform standard that can be applied universally will result, for the assimilative capacity of areas of the environment varies a great deal. The amount of pollutant that can safely be diluted, degraded and recycled in the Atlantic ocean is much greater than that one would wish to accept in a land-locked sea. The volume, rate of mixing of water masses, rate of temperature-dependent processes, and nature of the ecological systems involved in the Baltic are very different from those of the Mediterranean or the Persian Gulf. The regulation of pollutant discharges to these waters similarly needs adjustment to local conditions. It is obvious that the same must apply with even greater force to lakes, rivers and streams, whose physical and biological characteristics are almost endlessly variable.

In practice, it is difficult to determine with confidence the assimilative capacity of many areas of the environment and there is a common need to bring in control measures, often based on intuitive judgements, as a precautionary step. Standards tend, therefore, to be set arbitrarily, and only later refined as scientific knowledge develops. There are, perhaps, two divergent philosophies that appear at this point.

On the one hand, it may be argued that pollution control is costly and that no nation has limitless resources to devote to it. One should assess priorities with feet firmly on the ground, and the ground must be proper scientific evidence that harm is being done to man, resources, or amenity, by a pollutant at the levels now attained or imminent. This has tended to be the British approach, and it explains why more stress has been placed, under British conditions, on the control of pollution of inland waters, which must be cleansed if we are to meet our forecast demand for supply, than on curbing motor vehicle exhaust pollution which has not been shown to be a hazard to health under present conditions in the United Kingdom. The other philosophy is different. It takes as its starting point the undoubted fact that many pollutants are certainly not beneficial; they are potentially damaging, and many of them are messy, smelly, and unwelcome. Therefore, if it is technologically practicable to reduce their levels in the environment at a cost that is not prohibitive, it is worth doing it. This philosophy governs the approach in Britain to the control of gaseous emissions from our main industries under the Alkali etc. Works Act (1906 and 1966); the Inspectorate responsible for enforcing the act must employ the best practicable means to bring down the levels of pollutant emissions, and they do not require medical evidence of damage in order to call for the adoption of a new and more effective process.

By and large there is much to be said for a blend of both approaches. Obviously, if damage is already being done, it must give high priority to a control scheme. However, if practicable means exist to abate a nuisance, it is sensible to employ them. It may make economic sense too (although this is an aspect I have not time to cover today), for it may well mean that the community at large is relieved of real costs arising through the wide dissemination of dirt, smell, or noise, and the costs of control of these disbenefits become associated with the costs of production of the product in whose making they are generated, and hence paid for by the people who buy the main product rather than by those who simply live downwind from the factory concerned.

THE NEED FOR MONITORING

We come back last to measurement of pollutants, because programmes of survey, surveillance and monitoring must be designed to meet the requirements of a user – commonly a Government, or a governmental authority charged with ensuring that people, resources and amenity receive adequate protection, and that set standards are therefore appropriate and attained.

Surveys within a country are certainly desirable to determine how real a pollution problem is, and how far it is likely to conflict with human well-being or the wise management of a natural resource. Pollution surveys should be linked to resource surveys, for both are aspects of the same business: sensible planning. Surveillance of trends is likewise vital as a part of the planning of the use of national and regional resources, and for the apportionment of priorities in the pollution control field. In this context the time scale of environmental management must not be forgotten. It takes a very long time indeed to carry through a major environmental management scheme from inception to operation. The environment we are going to have in 1980 is already largely determined; if we are to have a cleaner world in 2000 we have to start planning now, on a rational forecast of trends. This makes the need for surveillance obvious.

It also emphasizes the need for proper analysis of the processes of interaction between living systems and pollutants, and the development of adequate models to improve prediction. How useful is it at present to devote much energy to measuring pollutant levels in air and ocean when we are unsure of the significance of the figures we obtain? Unless we have more research on such basic matters, we shall be ill-placed to set reasonable standards or to interpret the processes displayed all about us. Nor shall we be able to design sensible monitoring systems.

Monitoring is needed now in order to relate what is going on in the environment to our efforts at pollution control, and to indicate whether we are winning or losing – and if the latter, how badly. At an international level, it is reasonable for countries to join together to survey and monitor what is happening in the air and ocean that are shared resources of global character. A scheme of monitoring of atmospheric pollution has already been drawn up by the World Meteorological Organization; it is noteworthy, in contrast, that a specialist panel of the Food and Agriculture Organization at a meeting in December 1970 concluded that an oceanic monitoring scheme should not be designed until further basic surveys and research had been conducted. We need international cooperation to survey, watch over, and monitor levels of pollution that are of genuine international concern because they affect the common stock of air and ocean, and might, if unchecked, disturb their balance to the detriment of all mankind. International operations are complex, however, and one basic rule in science is that one should not make either explanations or research programmes more complicated than is essential. I believe this applies here. Let us recognize that a large part of pollution affects relatively small areas near to its source, and that this is best studied on a local or national basis according to the judgement and priorities of the Government concerned. Other problems may affect regions; this is so with shared lakes and rivers such as the Great Lakes of North America, the Rhine, the Danube, or the Nile, and land-locked seas such as the Baltic or Mediterranean. For there, regional studies and regional control agreements operated by the nations directly concerned make best sense. By all means let us interchange scientific data and administrative experience as widely as possible, but let us be wary of constructing world-wide monitoring programmes when the present and forseeable problems are essentially regional or national in character.

If we are to have global, regional or even nationwide programmes of this kind, in the end one comes inescapably to the brass tacks of competent scientific design and adequate methodology. If data are to be gathered in many centres and processed by different laboratories, it is vital that the same things are truly being measured; that if the techniques are not identical, at least the data are intercomparable and of known accuracy. Here there is still a need for scientific effort, of the kind this present Symposium exists to fulfill, for it is at best a hindrance, and at worst a gross deception, to plan massive national and international schemes of pollution control if the basic surveys, analyses of trends, and monitoring of effects depend on inadequate techniques. Our responsibility here is to see that this is not so; that if something is just not feasible at present, it is not written into a programme, and that if a figure is only reliable within 40 or 50 per cent, this degree of error is clearly attached to it and it is not used in the making of judgements requiring a higher order of accuracy. This may sound trite and obvious, but it is amazing how often it tends to be overlooked. There is no substitute for scientific accuracy based on adequate techniques and good experimental design.

CONCLUSION

In conclusion: I have no prophetic or high-sounding message to give this meeting or the world. I think it may be better that I have not. For this subject of man's impact on environment through pollution has of late been the occasion for many dramatic exhortations, many prophecies of doom, and many sweeping generalizations. These may have been helpful in awakening people to the real need for wise management of the environment and of man's impact upon it. But I do not think we need many more such exhortations. No Government in possession of its senses would knowingly devastate the environment of its own or its neighbour's peoples, and few literate or responsible folk anywhere can doubt the real nature of the tasks that confront us. What we need is not exhortation but analysis: the sharper definition of priorities; the recognition of areas where new techniques are essential; the more effective interflow of information between scientist, policy maker, citizen and those still at school on whom the future rests. I have tried to bring out some of the questions we must strive to answer. For the next four days we shall be working at the real level from which progress must come: the critical, rigorous, endeavour of the individual scientist in the individual laboratory, whose work is fundamental to all the generalizations in the world.

SUMMARY

There is no single homogeneous category of pollutant. To be identified as such, a substance must simply have effects on man, resources or amenity that are unwelcome in the circumstances of the community concerned. There is a high component of social judgement in the situation.

Pollutants are measured in order to appraise the magnitude of present problems, forecast trends, comprehend effects, and monitor the effectiveness of control measures.

In predicting the likely seriousness of a pollutant, its toxicity, persistence, dispersal characteristics, reactivity, biodegradability, bioaccumulation and capacity for control are relevant. Often our basic scientific techniques for appraising these parameters are inadequate for the task.

There is likewise an element of social judgement in the severity with which the effects of a pollutant are regarded. Effects on man are placed highest in the scale. We still do not have adequate understanding of the nature of many chronic effects on man or living resources, and many standards that have been set are arbitrary and may have little validity.

It is very difficult, if not impossible, to appraise the real size and nature of a pollution problem without background knowledge of ecological and physiological processes, and of natural trends in the environment. Spurious correlations in this area could well lead to a major error of judgement and waste of resources. Rigorous data that can be employed in sophisticated models are of high importance.

In establishing standards for permissible levels of pollutant in the environment, one must decide what part of the human or non-human living population to protect to what degree, and this is not easy or always logically consistent. The less basic scientific knowledge there is of the relationship between pollutant and effect, the wider the margin of safety that is needed. Logically, standards should be related to assimilative capacity of organism or environment and such standards must be highly non-uniform; there is no such thing as a single set of global environmental quality criteria. Under present uncertainties, however, it may be necessary to adopt a philosophy of using best practicable means to abate an emission even when there is no proof of damage.