Prime Minister (2): To note. This summarises the work on technology and the environment which Dr Nicholson has been leading, as agreed at the London Economic Summit.

W0935

THE PRIME MINISTER

13 December 1984

TECHNOLOGY, GROWTH AND EMPLOYMENT WORKING GROUP - FULFILMENT OF ENVIRONMENTAL REMIT TO THE GROUP FROM THE LONDON ECONOMIC SUMMIT

1. The Technology, Growth and Employment Working Group was invited by Heads of State and Government at the London Economic Summit to prepare a report on the current state of scientific and technical knowledge in the environmental area, and in particular, to comment on the scope for international collaboration, including industrial collaboration. You will recall that this request was made principally on the initiative of the United Kingdom, partly because we were anxious that the political pressure for international environmental action was ill-supported by scientific and technical knowledge.

2. The Group was asked to report by the end of December 1984, which ensured that the work was conducted under UK Chairmanship. I have convened the Group on three occasions since the London Economic Summit, and I am pleased to report that we are very near to concluding our work, and that a report will be in Sherpas' hands by the date requested.

(Conclusions only - the report is very long)

3. I attach a copy of the latest draft of the Report which I expect will be modified only slightly before constituting the final report. The Report consists of a general section and then a group of six Technical Reports on key environmental topics identified by the Working Group, namely atmospheric pollution, toxic and radioactive wastes, marine pollution, pollution of soils and waters, appropriate land husbandry and climatic change.

4. In each area, the Technical Reports provide a synopsis of the state of current scientific knowledge drawing on the most up-to-date research in the Summit countries and elsewhere, a summary of current international collaboration and a series of specific research areas where international collaboration could be developed. United Kingdom experts together with two of my own staff were responsible for the initial drafting of these reports, and, although the material is necessarily in condensed form, they have been widely

acclaimed by experts in our partner countries as excellent summary documents. My own view is that they will form valuable reference material for some time to come.

5. The general Report draws on the Technical Reports, but does not confine itself to a summary of those reports. Rather it sets environmental policy issues within a wider context by considering the relationship between technology, growth and employment in the environmental field. The general Report, concluding that science and technology is a crucial element in environmental policy making, explains how science and technology can forge a link between economic goals, such as growth and employment, and goals of environmental protection. In commenting on the complex nature of many environmental problems currently facing policy makers, the Group recognises that there are few if any easy solutions, and, because of this, considerable stress is laid on the importance of education and communication in this field.

6. On the specific aspects of the Technology, Growth and Employment Working Group's remit, the Report draws attention to the conclusions about international research collaboration in each of the Technical Reports. Rather than isolating just a few of these for special recommendation, the Group proposes that international organisations already active in environmental research and development should study the Technical Reports with a view to incorporating the relevant recommendations within their own forward plans. However, there is one specific area on which the Group focussed, that is the improvement of the accuracy and comparability of measurement techniques, where it felt there might be a need for a fresh initiative. The Group has devised draft terms of reference for such a study, and suggests eliciting the responses of international organisations to the proposal, prior to consideration of establishing the study as a project of the Working Group. The Working Group intend returning to these matters when international organisations have had the opportunity to comment, so that it can assess what, if any, further action is required.

7. The overall conclusions and recommendations of the Group are set out in paragraph 47 and 48 of the Report, and as an Annex to this minute.

8. I am copying this minute only to Sir Robert Armstrong.

RBN

Dr R B NICHOLSON
Chief Scientific Adviser

W.0934 13 December 1984

MR BARCLAY, NO 10

This minute and attachments need not trespass on the Prime Minister's valuable time in the next few days, but I felt I should, as a courtesy, send a copy of our report before it goes to the Summit countries generally through the Sherpas. The conclusions and recommendations are reproduced in Annex A of my minute.

RBN.

ROBIN B NICHOLSON

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DR R B NICHOLSON
Cabinet Office

This is simply to record that the Prime Minister has seen and noted your minute of 13 December about the Technology, Growth and Employment Working Group. She was grateful for this account.

Timothy Flesher

24 December 1984

TFS.

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The Technology, Growth and Employment Working Group was established by Heads of State or Government at the 1982 Economic Summit in Versailles. It has since presented two general reports on technology, growth and employment, published in the United Kingdom by HMSO as Cmnd 8818 and Cmnd 9269. The Working Group's members are drawn from senior scientific and technical advisers to Heads of State or Government from the Economic Summit countries. During 1984, the Group was chaired by Sir Robin Nicholson, Chief Scientific Adviser, Cabinet Office.

Enquiries arising out of this Report should be made to the Science and Technology Secretariat, Cabinet Office, 70 Whitehall, London SW1A 2AS.

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REPORT ON THE ENVIRONMENT BY THE TECHNOLOGY, GROWTH AND EMPLOYMENT WORKING GROUP

Preface

i. In its report to the London Economic Summit in 1984, the Technology, Growth and Employment Working Group identified environmental protection as one of the key science and technology areas which relate to economic growth and employment.

ii. The Heads of State or Government accepted the importance and timelinesss of the issue and invited the Working Group to undertake a special study of the role of environmental factors in economic development. The communique of the London Summit contained the following passage:

> "We recognise the international dimension of environmental problems and the role of environmental factors in economic development. We have invited Ministers responsible for environmental policies to identify areas for continuing co-operation in this field. In addition we have decided to invite the Working Group on Technology, Growth and Employment to consider what has been done so far and to identify specific areas for further research on the causes effects and the means of limiting environmental pollution of air, water and ground, where existing knowledge is inadequate, and to identify possible projects for industrial cooperation to develop cost effective techniques to reduce environmental damage. The group is invited to report on these by the 31 December 1984."

iii. In fulfilling its remit, the Technology, Growth and Employment Working Group not only focused on environmental science and technology, but tried to set this in its broader context, that is its relationship to economic growth and employment.

iv. The Working Group met three times since the London Summit to undertake this study. Our findings are set out in this report.

Introduction

1. Environmental protection is a necessary and vital concern of Governments. Giving environmental policy its due political weight is essential because the successes and failures of environmental protection are so far reaching. Successes can be spectacular. Learning the lessons of the dust-bowl, the extraordinary growth in agricultural output in our countries has been achieved without creating problems on a comparable scale. Equally, there have been dramatic reductions in many of the more severe forms of pollution, for example smog and heavy contamination of freshwaters and the sea. But failure to consider or appreciate the environmental consequences led to the gross pollution during the first half of this century associated with industries such as coal and steel, the legacies of which we live with today in the form of scenes of ladscape devastation in areas of heavy industry, continuing air pollution, and damage to historic monuments, despite major campaigns to restore the landscape and clean up the environment. And there continue to be pollution problems, relating to current patterns of energy consumption, transport and manufacturing processes.

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2. Environmental policy making is a complex area, where economic, social and scientific factors must be balanced. Moreover, environmental problems are, themselves, inter-related, and call for a comprehensive and anticipatory approach to policy making so that the problem is not transferred from one domaine to another. The relationship between man's economic activities, in the form of exploitation of natural resources and manufacturing, and possible environmental damage as a result of these activities, demands systematic and rigorous decision making in all economic areas. While it is unrealistic to hope to eradicate all environmental hazards, a comparison of competing options in terms of relative effects on the environment helps pinpoint which options are least damaging. Decision making in the energy field illustrates this point well, since one man's energy availability is often another man's pollution.

3. A further reason for giving environmental protection high priority is that many forms of environmental pollution are readily observable, have a discernible effect on people's livelihood, health and amenity and, understandably, give rise to public concern. This places a special responsibility on policy makers to communicate with the public, but the difficulty of conveying the complexity of environmental processes and the uncertainty of the efficacy of abatement actions mean that political decisions often have to be made in an emotionally charged atmosphere, or on the other hand, in advance of widespread public concern in order to avoid future economic and social costs. The paper, thus, argues for a continuing active role by the international science community in providing the knowledge and technological tools required by decision-makers to anticipate and address environmental problems through enlightened and effective policies and programmes.

4. Giving environmental policy due prominence on the political agenda is likely to put Governments in a stronger position to anticipate difficulties and take preventive action to avoid environmental damage rather than to respond to the damage once it has occurred. Many problems are readily soluble if tackled at an early stage. It will also be vital if effective international action is to be agreed upon. It is becoming clearer that a global approach is needed in order to combat environmental deterioration, so international consensus about the importance of the environment is an essential prerequisite to the coordination of national policies which will have necessarily been developed initially in accordance with national needs.

The Environment, Economic Growth and Employment

5. The protection of the environment and the development of the economy are frequently, though mistakenly, regarded as competing goals. The Working Group's view is that it is possible to achieve and reconcile both economic and environmental goals through the medium of the proper use of science and technology. In effect, science and technology can provide a bridge between policy in the two areas.

6. Questioning the value of the industrial society because of environmental problems leads us to no easy solutions. A return to more simple forms of life does not offer any realistic alternative, because satisfactory human living

conditions—this means work and prosperity for everybody—could not be ensured. On the other hand, there is nothing to be gained from closing one's eyes, for narrow economic reasons, to the implications of human activities for the environment. In turn, environmental improvement or deterioration has an impact on the individual and on society. Long-term economic growth will only be possible if we protect and conserve the resources which underpin prosperity. Economic and ecological interests must and, we believe, can be reconciled.

7. One reason why the environment is abused is that it is a commodity for which people have not had to pay, and do not have to pay, either at all or not very much, because there is no market for it. Thus, environmental policy has to set high levels of environmental quality, which will then give rise to high barriers—particularly economic barriers—for an abuse of environment. Under these conditions, economic growth is not opposed to environmental protection; on the contrary, it makes easier an increase in the amount of resources devoted to environmental protection.

8. The grosser forms of environmental damage, largely starting with the energy-greedy industrial processes of the late 19th and early 20th century, and the costs associated with remedying that damage, must not be taken as inevitable events which will continue after improved and energy-saving industrial processes for the existing production and manufacturing sectors are introduced, and which will be repeated as new industrial processes are developed. Traditional industrial sectors can be made compatible with good environmental practice. And as far as new industries such as information technology, biotechnology and electronics are concerned, even whilst they are in their infancy, we should be considering their environmental consequences and, without stifling their development, explore and design a regime which will be compatible with sustained high environmental quality.

9. The way ahead is for high environmental quality objectives to provide the incentive for innovation and for the development of techniques which are clean and, at the same time, efficient in the use of resources. Equally, it will be possible to establish those objectives because of the contribution to our understanding of processes and technical development made by research and development. Environmental policy making is a prime example of an area in which both social and economic goals can be reached on a sound scientific base. Although the policies and standards must be the responsibility of each government, and will be based one each country's unique characteristics, circumstances and stage of development, the nature of environmental issues is such that they affect the environment and economies of other countries, and must be based on shared international scientific knowledge and agreed common principles.

10. Stricter environmental protection regulations have an impact on individual companies, on their employees, and on the costs of producing goods. The additional costs which may result from production methods which are environmentally sounder must be borne by the polluter and financed by way of prices. There is no doubt that, in some cases, we are talking about major structural change and the transitional period requires careful management. It is important to pursue an economic policy which provides companies with the necessary latitude so that they can adjust without a large degree of friction.

11. In the conclusions of the Conference on 'Environment and Economics' (June 1984), the OECD quoted examples of growth sectors such as regular plant maintenance, employment in monitoring services and production and export of environmental protection equipment. But, given the extremely complex processes of adjustment, it is difficult to draw up a balance sheet of the positive and negative structural effects of environmental policies. We conclude that we need not be pessimistic about employment effects. The better the political framework for industries affected by tighter environmental controls to adjust positively to structural changes, the less will be the negative and the stronger the positive employment effects on industries providing environmental protection goods and services. Also, because the consequence of well-founded environmental practices will be a more efficient net use of land and resources, the long-term effects on the economy will be beneficial.

The Role of Science and Technology

12. In calling for an assessment of environmental research in their Communique from the London Economic Summit, the Heads of State and Government gave recognition to the important role science and technology must play in finding solutions to environmental problems. In the previous section, science and technology were referred to as a bridge between the environment and economic growth because they lead to an understanding of cause and effect, and the development of cost-effective means to intervene successfully, through preventive or remedial action. An essential feature of a policy based on anticipation and prevention is an active research and development programme. Further, improved cost-benefit analysis techniques, deriving from inter-disciplinary research, are important tools of environmental policy.

13. It is clear that the Economic Summit nations have a strongly shared interest in this sector. Historically, our nations have been at the forefront of developing the knowledge, the technologies and the methodologies that have been applied throughout the world in addressing environmental threats, through strong national research and development programmes and institutions. We also maintain a broad range of bilateral agreements, under which the tools and results of these national efforts are exchanged; and we support and are active in a range of multilateral institutions which carry out programmes of a scientific nature.

Current State of Scientific Knowledge

14. The Working Group agreed its central task was to assess the state of scientific knowledge in six key areas which it identified:

atmospheric pollution
toxic and radioactive wastes
marine pollution
pollution of soils and waters
appropriate land husbandry
climatic change

This assessment has elucidated the degree of present understanding about the processes of environmental damage, which fields of research are currently the most significant, and where the principal gaps in our knowledge are. The Working Group went on to document some of the most important examples of current international collaboration in these areas. The detailed presentation of these matters are to be found in the Technical Reports 1-6, which represent the backbone of the Working Group's study and on which this brief report is founded.

15. The Working Group noted, with satisfaction, that there was considerable agreement between specialists in our countries on the state of scientific knowledge and the important scientific priorities, which is an encouraging sign for future collaboration.

16. Although in all the fields considered by the Working Group there are active research programmes which are continuing to add to the fund of scientific and technical knowledge, there are considerable differences in the depth of our understanding of different environmental problems, of the nature and timescales of the problems, of the technical means of overcoming them, and hence differences in the relationship between science, technology and policy making. This reflects variation not only in the extent of our scientific knowledge, but also in the perceived complexity of the problem. As scientific knowledge of a particular problem increases, an increased understanding of its nature will normally narrow but may sometimes widen the perceived gap between solving the problem and current knowledge, revealing wider ramifications and increased complexity.

17. The problems which have received the most attention are those where the environmental damage is already taking place, but where there are appreciable gaps in our scientific knowledge of the processes, and inadequate development of the technology to mitigate the damage. Many examples of these problems, involving pollution of air, land and water, can be found in the Technical Reports; a good example is the problem of air pollution, particularly acid deposition, which is associated with damage to the natural and built environments (Technical Report 1). There is scientific uncertainty about the physical, chemical and biological processes leading to the observed damage, and lack of agreement about the most appropriate technologies to overcome the damage. These uncertainties and disagreements do not remove, however, the need for decisions on action, but illustrate the importance of risk assessment as a tool in environmental decision making.

18. In contrast are problems not of today, but of tomorrow, where the uncertainty is either over the processes and effects, or over the technology to overcome the effects. Of particular concern to the Working Group in this regard, is the prospect of inadvertant, irreversible climatic change. There is now scientific agreement that carbon dioxide in the earth's atmosphere is already increasing at such a rate that towards the end of the next century its concentration will be double that at the start of the industrial revolution (Technical Report 6). It is believed that this will lead to a warming of the earth's atmosphere, but scientific knowledge does not yet provide confident predictions of the details of the effects on climate, sea level and agriculture. There may be a temptation to ignore the need for decision making and action as there are, as yet, no palpable effects. However, present information suggests

that, by the time changes in climate from this cause is clearly evident, the processes leading to further change may well be irreversible. There is an appreciable possibility that the environmental effects will be of such a nature and magnitude that the whole international patterns of settlement, agriculture and trade are altered. There is also concern about the depletion of the stratospheric ozone layer which shields the earth from harmful ultraviolet radiation (Technical Report 1). In another area, the rapid growth in the development of biologically engineered products promises to bring benefits, but we will want to analyse in advance of their widespread use any possible health and environmental risks of these agents. Problems such as these are complex and far reaching, and, while every effort must be made to increase scientific certainty, action may well be needed before there is full scientific knowledge.

19. Some environmental problems are well understood scientifically, but are legacies of past actions and their solutions are hindered by the lack of suitably developed technology or by cost. Problems in this category, which the Working Group have considered, include the inadequate disposal of some kinds of toxic wastes (Technical Report 2) and the use in public and private buildings of asbestos (Technical Report 1). In general, once the existing environmental damage has been overcome the same problem should not arise again, so long as education, communication and political will allow countries to benefit from the lessons of the past.

20. Most of the environmental problems which the Working Group has studied, however, concern environmental damage which exists today and is likely to continue. Our knowledge of the science of the processes involved and of the technology necessary for abatement is sufficient to indicate the broad approach of action needed but insufficient for confidence that the problems can be solved. Many examples are discussed in the Technical Reports and include the contamination of groundwaters (Technical Report 4) the inappropriate disposal of wastes (Technical Report 2) and many forms of pollution of the air (Technical Report 1).

21. In some areas discussed in the Technical Reports, the state of scientific knowledge, though still being improved, is sufficiently advanced to propose solutions, but decisions or action may be inhibited by political, social or economic factors. Examples are provided by some of the failures of land husbandry (Technical Report 5) where the main barriers to overcoming them are not primarily a lack of understanding the scientific processes or of appropriate technology but a combination of economic judgements, social patterns and lack of understanding by decision makers. Another example is the pollution of coastal and estuarine waters (Technical Report 3) where the main impediments to progress are often the high cost of abatement technology and a lack of awareness by the public or the authorities of the hazards.

22. With regard to human health, the focus has changed from the immediate effects of pollutants to subtle effects which may become apparent only after relatively long-term exposure. It is often extremely difficult to establish the causal links between pollutant exposure and chronic effects with any great certainty. Epidemiology, though an extremely important discipline, does not

necessarily provide the sensitivity needed to establish causal relationships, whilst direct toxicological testing is sometimes impractical or unethical. For this reason, there is a need to develop better methods of predicting the toxicity of and exposure to, for example, chemicals to provide accurate and inexpensive ways of determining water quality. Especially in complex experimental areas such as these, the sharing of national research results and the avoidance of duplication is a valuable step forward. And yet, decisions on control measures may have to be made, not on the basis of full scientific knowledge, but of risk assessment and political judgement. The importance of encouraging advances in risk assessment techniques is underlined by the fact that even in fields where scientific data gathering is less constrained, decision making in environmental policy also involves the management of uncertainty.

23. The magnitude of some environmental problems is partly determined by public perception. As is shown in Technical Report 2, the scientific issues associated with the disposal of toxic and radioactive wastes are broadly similar. However, the public perceptions of the problems associated with these classes of wastes are very different and are appreciable factors in environmental decision making.

24. The Working Group concludes that the state of scientific and technical knowledge varies greatly between environmental issues. This does not so much reflect differences in quantity or quality of research so much as in the nature and complexity of the different issues and their environmental effects.

International Research Collaboration

25. In all the areas of environmental research considered by the Working Group there is extensive international research collaboration. This can be at many levels: from bilateral programmes involving individuals in two countries to major programmes involving international organisations such as agencies of the United Nations. The Working Group has concentrated on the latter end of the spectrum.

26. International bodies may foster international research collaboration by the direct funding of research programmes, or by the encouragement of cooperation and the exchange of national research results. An example of direct funding is provided by the Environment Programme managed by the Commission of the European Communities. An example of the latter is the World Climate Programme (Technical Report 6) in which several international agencies organise meetings for the exchange of scientific information and coordinated planning of their respective projects. Different international research programmes have different underlying objectives which depend on the nature of the scientific problems, the organisation of national research problems, and factors of history.

27. The international nature of environmental problems makes international collaboration especially important. Its review of international research has convinced the Working Group of the value of international cooperation to enhance environmental research and make it more useful. There is no substitute for the exchange of information and experience in understanding,

and then combating the global, regional and transboundary problems mentioned above. But even on issues that are confined within one nation's boundaries, the benefit of information exchange is clearly evident for expanding scientific knowledge, methodology and approaches for finding alternative solutions or eliminating duplicatory work and saving precious financial and manpower resources.

28. The Working Group has noted the extent of international effort represented by the many existing international science and technology programmes documented in the Technical Reports. Partly for this reason, we have not proposed new institutional forms of collaboration, but we advocate the fuller and better use of existing international organisations and their programmes. The interrelationship of environment problems means that there will necessarily be some overlap between the work of international organisations. However, it is important to work to reduce unnecessary duplication, to ensure the effective use of limited resources. This will involve the periodic re-examination of international activity. From the Working Group's scan of current programmes, there seems to be scope for greater concertation between the bodies concerned.

Areas for Further Research

29. The Working Group was invited to consider areas for further international cooperation. Each of the Technical Reports discusses in some detail the need for further international research. In sum, the Working Group has identified 69 areas of research, where greater international cooperation is justified. The proposals are made in the Technical Reports and would, in most cases, represent natural developments of current programmes in such bodies as OECD, UNECE, UNEP and ICSU. They might usefully be treated as items for consideration on the scientific agenda of such bodies. All are priority areas, but the degree of priority attached to them by different countries, or by different international groupings will depend on differing perceptions of their policital sensitivity, the urgency of the problem and their scientific importance.

30. The Working Group therefore proposes that international bodies dealing with science and technology collaboration in the environmental area should have the opportunity to study our full report and, subsequently, convey their reactions to the Working Group. In many cases, international bodies may wish to signal which of the priority areas in the Technical Reports have special relevance to their own programmes and the prospect for incoporating such priorities into their forward plans. The Working Group, confident that existing international bodies will respond positively to most of the suggestions, will be interested to receive such reactions and then to decide if any further action ought to be taken on a Summit-wide basis.

31. In addition, the Working Group invites comments from international bodies concerning the measurement practices and techniques fundamental to all environmental research.

32. The Working Group noted a consistent theme in the Technical Reports, which is the importance of having available appropriate internationally recognised measurements in which they could have confidence. In several scientific

areas, the interpretation of data is severely hampered by uncertainty about the compatability or robustness of the measurements made in different parts of the world. In others, in order to reach conclusions about action, there needs to be improved accuracy of measurement.

33. This is far from a glamorous area of research, but it is one in which serious international study might be of enormous value. It is a theme which may be of interest to more than one international group, and the Working Group has discussed setting up a study-group, on the understanding that it would relate closely to all interested bodies and would make its findings freely available. Proposed terms of reference are attached at Appendix A. As part of its preparations for setting up this study group, the Working Group invites comments on the suggestion, particularly how worthwhile this would be, and how the interests of international organisations can be fully taken into account.

Areas for Industrial Collaboration

34. At one level, the remit to consider industrial collaboration might be interpreted as spotting opportunities for companies in different countries to pool their efforts in working up technologies and products associated with environmental protection. The issues discussed in the Technical Reports clearly cannot be dealt with unless we have cost-effective technical means to deal with waste and pollutants and to prevent bad resource management. Whilst the Technical Reports refer to many areas within which there may be opportunities for international industrial cooperation, the choice of those areas, indeed the choice to collaborate, rests with industry. Moreover, the pressure to collaborate must be balanced against the need to promote competition.

35. Therefore, the Working Group considered it appropriate to look particularly at the relationship between Government and Industry, and how collaboration there might set the scene for effective invironmental policies.

36. Governments are responsible for setting environmental quality standards, and industry must develop techniques which enable it to meet those standards. It is imperative that standard setting should proceed in the knowledge of the implications for industry, and against a timetable which gives industry space to adapt to new standards taking account of industrial renewal cycles. This calls for an active dialogue between Government and industry.

37. In this framework the Working Group agrees that the market and industrial competition can provide appropriate and effective mechanisms for the pursuit of environmental goals, given a structure which allows a realistic value to be placed on environmental resources and which encourages the profitability of good environmental practices. In this way, industry will control its harmful environmental practices not only when it is forced by public pressure or by law to do so, but because its economic interests also lie in sound environmental practice.

38. Some of the success stories in environmental protection reflect the value of effective collaboration between Government and industry. The participation

of small and large firms in regional planning, land zoning, and in taxation and land valuation schemes can parallel discussions at a national level about the implementation of standards. Industrial participation in long-term planning is equally desirable, eg in managing energy use and conservation through advances in construction practices, developing modes of transport etc.

39. The international dimension of environmental protection measures makes the collaboration between Government and Industry all the more important. The Group agree that harmonised international approaches are vital, and that their framing should leave room for industrial competition and be designed to take sufficient account of particular characteristics of individual countries, in terms of their resources, demography etc. In effect, decisions on such matters should take into account best practicable environmental options.

40. The Working Group noted the relevance of the conclusions of the recent World Industry Conference on Environmental Management (November 1984). This Conference examined the scope for international coordination involving the private sector, arriving at broadly similar conclusions to this report about the necessity of interaction between Governments and industry on an international basis, and identifying a number of priority areas for future collaboration.

Education and Public Opinion

41. An essential element in effective environmental policy is education. This means, not simply the accumulation of environmental information by the public, but the development of an awareness of the environmental aspects and consequences of almost all activities, the creation of an intelligent attitude to the environment as a necessary but not invulnerable support base for the economy and a realization that environmental systems are inter-related and affected by individual as well as corporate and Government actions.

42. Environmental education will be all the more important in years to come because the environmental challenges of the 1980s are more complex than those addressed in previous decades. There is a need to inform the public about the evidence of contamination, the assessment of risk, the correction of damage, preventive measures and the cost, but these are all difficult areas of science, technology and public policy. We are frequently operating at the frontiers of knowledge, and critical decisions for governments may rest on controversial scientific judgements. Decision making also takes place within limited time constraints, which, in a democratic society, calls for a ready appreciation of the issues on the part of the public. The education and research enterprises must be part of an iterative process. Significant research findings, as well as up to date material on the monitoring of environmental hazards, should be widely available and in a form accessible to the public.

43. The formal education sector must play a significant role in this matter. In schools, colleges and universities there is a need to place the economy and social development in an environmental context. For those with a continued professional involvement, including engineers, economists and agriculturalists, in-service training is needed to support decisions which take into account,

not simply the more obvious forms of environmental impact, but the more subtle inter-relationship between industrial operation and the environment and its reactions.

44. The role of the media is also crucial. The practice whereby environmental reporting is confined to sensational events undermines the growth of critical awareness of the interplay between man's economic activities and the environment. But inexplicit and incomplete reporting of Government material on environmental hazards has possibly undermined confidence in Governmental bodies as interpreters of relevant material. Insofar as much of this material is generated within Government sponsored programmes, agencies must continue to be active communicators, and maintain confidence through a record of open and intelligible reporting. Industry, too, must pay attention to communication, and learn from those companies which engage in effective and open dialogue, listening to the environmental concerns of those affected by new plans, and benefit from public confidence in their care for the environment.

45. It would be desirable for the planning of international programmes of research and development to take account of the importance of educational aspects, through incorporation of training elements, where appropriate, in the programme and by giving sufficient priority to dissemination of results.

46. The benefit of such an educational effort will be realised in increased public understanding of environmental policy decisions, and more effective and informed participation in the decision making process.

Conclusions and Recommendations

47. The Working group has concluded that:

1. economic and environmental policy can be brought closer together, through the medium of science and technology,

2. long term economic growth is only possible if we protect and conserve the environmental resources which underpin prosperity,

3. economic policies should provide companies with the necessary latitude so that they can adjust to stricter environmental regulations without a large degree of friction,

4. placing an appropriate and realistic value on environmental resources can provide the framework for achieving environmental quality objectives within the context of a market economy,

5. high environmental quality objectives provide a valuable incentive for innovation in science and technology,

6. continuing high priority must be given to science and technology in relationship to the environment, in order to provide a sound basis for environmental policy making,

7. international cooperation in environmental science and technology is essential, not simply to avoid duplication and to make the best use of financial and manpower resources, but because the nature of many environmental problems demands an international approach to research development,

8. existing international organisations engaged in sponsoring such collaboration are well-placed to undertake the work that is needed, and no new institutions are needed, but there is scope for greater concertation between the bodies concerned,

9. internationally consistent techniques and practices of environmental measurement are necessary if research results are to be truly comparable and if environmental standards are to be effectively maintained,

10. education has an important role in environmental policy, which places special responsibility on Governments, industry, educational institutions and the media.

48. The Working Group, while drawing attention to its conclusions and commending them to Heads of State and Government, has confined its recommendations to its specific remit on science and technology. We recommend that:

1. relevant international organisations study the list of priority topics in the Technical Reports, with a view to establishing these in their forward plans, as appropriate,

2. the Working Group reconvenes in due course to consider and determine what future action is necessary in the light of the responses of the international organisations to the priority topics and their comments on the proposed study group on the techniques and practices of environmental measurement.

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APPENDIX A

PROPOSAL FOR A STUDY OF THE IMPROVEMENT AND HARMONISATION OF TECHNIQUES AND PRACTICES OF ENVIRONMENTAL MEASUREMENT

Background

There are two reasons for suggesting the establishment of a study in this area. At a scientific level, the adoption of internationally consistent techniques and practices ensures that research results are comparable, which is particularly important in understanding cause and effect and in monitoring change. At a political level, accurate and compatible measurements are vital for the setting and monitoring of environmental standards.

Work Programme

The focus of the study would be to consider where there is a scientific requirement for improvement and harmonisation of the techniques and practices of environmental measurement, in particular where use should be made of new and sophisticated methodology. The study group is expected to identify those areas in which there is cause for concern about the accuracy, precision and sensitivity of measurements (physical, chemical or biological) and then to consider how best to encourage improvements so that these measurements are internationally compatible and recognised as authoritative.

Timescale

The study group would be asked to complete its work within two years and to make an interim report to the Technology Growth and Employment Working Group after one year.

Relationship with Other Nations and Organisations

As with several of the Technology Growth and Employment Working Group's existing areas for collaboration, non-Summit members may seek affiliation to the study group. The group would be expected to liaise with those international bodies which have a major interest in this field, in particular the United Nations Environment Programme and the International Council of Scientific Unions. Because of the wider international relevance of its work, the group would be asked to publish its final report and to bring it to the attention of bodies concerned with international norms of environmental protection, for example the United Nations Economic Commission for Europe.

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TECHNICAL REPORT 1

ATMOSPHERIC POLLUTION

Introduction

1.1. The initial stages of industrialisation often gave rise to incidents of gross air pollution with correspondingly large ecological and health effects. Such locally concentrated air pollution, at least for the Economic Summit Countries, is now rare, due both to the installation of appropriate abatement technology and to more efficient dispersal of pollutants so as to minimise ground level concentrations.

1.2. Attention is now turning to questions of possible long-term environmental effects of exposure to the currently relatively low levels of contaminants which arise from natural and, in particular, anthropogenic sources. Furthermore, as analytical techniques have improved, it is becoming increasingly possible to detect and measure in the air low concentrations of a number of chemicals from which there is experimental evidence of a hazard, under certain circumstances, to man or to the environment.

1.3. There is concern about atmospheric pollution from a long and varied list of chemicals. Of particular international importance are the sulphur and nitrogen oxides which, together with hydrocarbons (in particular halogenated and aromatic hydrocarbons), photochemical oxidants, metals and other substances, are the pollutants responsible for the various processes known as acid deposition which causes damage to a range of ecosystems (1, 2). Some atmospheric pollutants, for example lead, asbestos, and certain organic chemicals, still give rise to concern primarily on human health grounds. Another concern is about long-term changes to the atmosphere, such as the depletion of the stratospheric ozone layer. The issue of increasing carbon dioxide concentration in the atmosphere is addressed in Technical Report 6. At the other end of the scale, there is growing attention paid about air quality within buildings, where certain contaminants can reach concentrations far higher than in the open air. Atmospheric pollutants, when deposited, may also make a major contribution to the pollutant load of marine environments (see Technical Report 3).

1.4. This Technical Report concentrates on those air pollution problems which have a major international dimension. Those which involve long-term changes to the atmosphere are clearly of concern to all countries. More immediate problems such as acid deposition are of an international nature as the pollutants emitted to the atmosphere in one country may be transported to another country where there are adverse effects.

Atmospheric Pollution and Human Health

1.5. Although the main atmospheric pollution problems addressed in this Technical Report involve damage to the built and natural environments, it should not be forgotten that there are still instances of atmospheric pollution presenting a hazard to human health.

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1.6. Within the Economic Summit Countries, it has been demonstrated that the clear-cut acute effects of air pollution on health, linked with the former high concentrations of smoke and sulphur dioxide in towns, have been largely eliminated. For example, within the European Communities (EC) the limit values set for these pollutants in the 1980 Smoke and Sulphur Dioxide in Air Directive were based largely on findings from research work in the 1950s and 1960s, and they were designed to avoid both acute and chronic effects. In most areas these limits are being met, and the absence of frank health effects is a tribute to the success of both national and EC measures. There may, however, be chronic effects on health arising from long-term exposure to low doses. There are other pollutants in urban atmospheres derived from both stationary and mobile sources that can damage health at relatively high concentrations; but concentrations are rarely such as to suggest the likelihood of significant effects. However, there are some instances of contamination of the atmosphere where government action needs to be considered on a precautionary basis. Examples include lead derived from additives in petrol, indoor pollution from radon gas, dioxin from industrial or combustion processes, and asbestos dispersed accidentally in the work place or from building materials or from improperly controlled industrial wastes.

1.7. The prediction and detection of slight increases in the rates of common diseases, or of subtle changes in bodily functions, are matters of the greatest scientific difficulty; this is particularly the case with long-delayed effects and with any effects from complex mixtures of agents, each at a very low dose. Much fundamental research is required and there are difficulties to overcome before our understanding will make a major advance.

The Origins of Acid Deposition

Sources of Emissions

1.8. Although there are a large number of atmospheric pollutants which are implicated in the various processes described as 'acid deposition', the two most important acidifying agents are considered to be sulphur dioxide (SO_2) and nitrogen oxides (NOx). (NOx is defined as the sum of nitric oxide (NO) and nitrogen dioxide (NO_2).) It is a matter of considerable scientific and international importance to have data on the emissions of these pollutants for each country. However, as the methods of preparing emission data vary from country to country, a high priority is to produce accurate and comparable data for international comparison.

1.9. The main sources of SO_2 emissions are fossil fuel power stations, industry, oil refineries and commercial and domestic heating. The most recent SO_2 emission data for the Economic Summit Countries (3) are given in Table 1. In most cases reductions have taken place since about the middle 70s, with the United Kingdom, France and Canada showing the greatest decreases in emissions. SO_2 emissions from fossil fuel burning are a function of the sulphur content of the fuel.

1.10. The main sources of emissions of NOx are fossil fuel power stations, motor vehicles, and commercial and domestic heating. Data for NOx emissions in Economic Summit Countries (3) are shown in Table 2. The United Kingdom has shown little change in emissions over the past ten years but there is some evidence of increases in France, the Federal Republic of Germany, the United States of America and Canada. NOx emissions from fossil fuel burning are a function of the combustion technology, in particular temperature.

1.11. Hydrocarbons (HCs), which are another important component of the acid deposition processes, are emitted from a variety of sources, including distribution systems (for example for natural gas), motor vehicle exhausts, solvent evaporation, and miscellaneous industrial processes. Other organic compounds are emitted to the atmosphere from various industrial processes. Quantitative data on HCs, and other organic, emissions depend on different national data collection methods and are less readily available than data on SO_2 or NO_2.

Atmospheric Reactions and Transport

1.12. The environmental impact of air pollution can come either from the direct effect of primary pollutants (in particular SO_2, NOx and HCs) or from secondary pollutants formed by their subsequent transformation. Sulphuric and nitric acids (the principal constituents of 'acid rain'), and ozone (O_3) are examples of such secondary pollutants. Their formation is a complex combination of chemical and meteorological processes. Although research has greatly increased our knowledge in this field, there is still much to learn (4).

1.13. When mixtures of HCs and NOx are exposed to sunlight, HCs react with hydroxyl radicals (OH) to give organic free radicals (highly reactive chemical species). These then react with NO to form NO_2, re-generating OH and so continuing the reaction cycle. In sunlight NO_2 is itself dissociated to give NO and an oxygen atom (O), the latter then combining with ordinary oxygen to give O_3. The OH radical needed to start this process is formed in sunlight either from O_3 already present (from previous pollution or natural sources) or from minor constituents of vehicle exhausts, such as aldehydes.

1.14. Overall the photochemical process is fuelled by HCs and sunlight, and the NOx have both a catalytic and a terminating role. The latter results from the fact that NOx also react with the free radicals, terminating the O_3-forming cycle and being oxidised to nitric acid in the process. In addition, NO destroys O_3 in the dark giving NO_2 and ordinary oxygen. The overall effect of these photochemical processes is not only to form environmentally active NO_2 and O_3, but also to oxidise NOx and SO_2 to nitric and sulphuric acids respectively, through reactions with hydroxyl, O_3 and hydrogen peroxide.

1.15. It is important to appreciate that the reactions leading to the formation of secondary pollutants can take place over a period of time as an air mass moves, and that a pollutant such as O_3 can be formed many hundreds of kilometres away from the sources of the primary pollutants. It is also possible that secondary pollutants are formed from primary pollutants each of which is derived from a different country.

1.16. The complex chemical and meteorological processes involved in these atmospheric transformations can best be addressed by the construction of computer-based mathematical models, and by the verification of these models using tracers such as sulphur hexafluoride. Such models have an important role in developing a better scientific understanding of the basis of possible control options. For example, the model developed at the Atomic Energy Research Establishment (Harwell), using data pertinent to conditions in the United Kingdom, indicates the importance of controlling HC emissions if the formation of photochemical pollutants is to be minimised. Indeed reducing the NOx to HCs ratio (for example, by selective control of NOx emissions) can lead under certain circumstances to an increase in O_3 formation. In contrast, models developed in the United States of America, using data relevant to local conditions, place greater emphasis on the need for NOx emission control. The development and validation of such models is vital both to obtaining satisfactory understanding of the atmospheric chemistry concerned and to developing effective emission controls relevant to local conditions and needs.

1.17. The European Air Chemistry Network (EACN), now superseded by the Monitoring and Evaluation of Pollutants in Europe Group (EMEP) of the United Nations Economic Commission for Europe (UNECE), has provided a long run set of data on precipitation acidity. Of 120 EACN sites 29 have shown a statistically significant increase and five a decrease of overall acidity. In Scandinavia during 1956-75 there was a 7% *per annum* increase in hydrogen ion concentration in precipitation, as compared with a year-to-year scatter of 50-100%. However, there has been criticism of the EACN results, mainly because of uncertainties in the measurement of pH in low ionic strength media, particularly with regard to the older data on which trend analyses depend. (Similar criticisms have been made of the measurement of pH of surface waters.) More detailed information on acid deposition in the United Kingdom has been published recently by the Warren Spring Laboratory (5); information on the acidity of precipitation has been published also in the United States of America and Canada. Comparison of these data sets can be difficult because of differences in measurement method.

The Environmental Effects of Acid Deposition

1.18. At pollutant concentrations normally encountered it is difficult to disentangle the relative roles of deposited acidity from the direct toxicity of atmospheric pollutants in gaseous form, such as SO_2, NOx or O_3, and other environmentally relevant factors such as land use changes and natural processes in soils and aquatic ecosystems. The position is further complicated as the environmental effects can either be direct, such as when dry deposition affects crops and trees, or indirect, such as when acidity influences fish through changes in the water chemistry or trees through soil characteristics. It is important to stress that acid deposition is not a uniform process; a wide range of different processes may be involved.

1.19. The scale of the problem is enormous, economically and socio-politically. The main areas of concern are the effects of acid deposition on forests, agricultural crops, freshwaters and buildings.

Effects on Forests

1.20. Although it is well established that high concentrations of SO_2, and other pollutants such as O_3, cause damage to vegetation, it is a relatively recent development to ascribe serious vegetation damage to current environmental levels of SO_2, NOx and acid deposition. Of particular interest has been the increasing evidence of serious forest damage in the Federal Republic of Germany (6) and in other countries such as Austria, Switzerland and, more recently, Sweden. Forest damage also occurs in some areas of the United States of America and Canada. It is not possible to ascribe this forest damage to any single cause: viral, fungal and insect attack and extremes of climate are all likely to play either a primary or secondary part. The obseved forest damage has been reported from such a large area and wide range of ecological conditions that air pollution is believed to play a significant role.

1.21. Acid deposition was first considered as a likely cause of the observed tree damage in the Federal Republic of Germany. One hypothesis involves damage to leaf tissues by the direct effect of SO_2 (or O_3) which renders them more liable to the leaching of magnesium and calcium by percolating acidified rainwater. Another hypothesis considers the direct effect of acid deposition to the soil, which eventually liberates aluminium ions from soil minerals. This aluminium is highly toxic to root systems and inhibits the uptake of divalent cations. This could explain the observed magnesium deficiency in the needles. However, this hypothesis is not applicable in all cases, although it may explain what happens in some areas.

1.22. Greater weight is now being given to the direct role of gaseous pollutants, particularly NOx and O_3. Thus concentrations of O_3 measured in the Black Forest (Federal Republic of Germany), in areas where damage has been occurring, are not only comparable to those observed in the United States of America where O_3 is known to cause forest damage, but also match concentrations observed in laboratory experiments which produce vegetation damage. Also the O_3 concentrations are consistently greater at higher altitudes in both the Federal Republic of Germany and the United States of America, and in both countries forest injury is observed to increase with altitude. There is as yet little direct experimental evidence to support the O_3 damage mechanism; the fact that similar forest damage has not been observed in the United Kingdom or Norway may be important in this connection.

1.23. Deposition of NOx and nitrates may also affect forests, in combination with the leaching of magnesium and calcium ions associated with acid deposition, by leading to nutrient imbalances which weaken the health of the trees.

Effects on Agricultural Crops

1.24. Although the impact of high concentration of SO_2, NOx, and O_3 on a range of crops is well established, the situation is less clear with respect to exposure at ambient levels (7). Not only are any effects small—much less than the effects of weather variation—but the results obtained from open top exposure chambers do not always reflect what happens in open field conditions. There is also some evidence of synergistic effects when mixtures of pollutants are present; for example the effect of O_3-SO_2 mixtures may be greater than that of O_3 of SO_2 alone. It is important to resolve these scientific uncertainties as even small yield reductions can translate into large costs on a national basis.

Effects on Soils

1.25. There are many processes within soils and their vegetation cover that can increase their acidity (and therefore that of run-off). The decomposition of plant material or humus releases nitrogen compounds which are converted to nitric acid, and the application of nitrogenous fertilisers to soils of limited neutralising capacity (for example, as a prelude to afforestation) can have the same result. The organic acids produced by the decay of leaf litter and plant residues can also contribute to soil acidity and the reduction of neutralising capacity. The bacterial oxidation of mineral and organic sulphides in the soil is yet another source of acidity.

1.26. Acidification of soils is a natural long-term process. The retreat of the glaciers at the end of the last Ice Age left soils that were high in unweathered minerals. Weathering and the continual percolation of naturally acid rain has oxidised and altered these minerals releasing acidic ions and removing some of them. This natural trend in acidification is most prevalent in areas of high rainfall, of geology which provides soils of only low neutralising capacity, and of poor drainage and low temperatures where organic matter, rich in humic acid, accumulates. This trend would be expected to accelerate if the acidity of the rainfall increased.

1.27. Forests act as an effective trap for acidic emissions, and it is found that water falling through the leaf canopy (throughfall) or passing down the main stem (stemflow), especially of old coniferous trees, is likely to be more acid than the incoming precipitation. Tree growth itself leads to the removal of metallic cations from the soil, which are replaced by hydrogen ions giving increased acidification. There are thus a wide range of factors involved in the acidification of soil which affect the significance of the deposition of sulphuric and nitric acids resulting from human activities, although the latter are considered to be the main component in the complex situation.

1.28. Chemical reactions between acid rain or snow melt and the soil are important. If the neutralising capacity of the soil is high, calcium and magnesium will be dissolved, but if the neutralising capacity of the catchment is low, for example being made up of hard granite rocks or sandy base-poor soils, then acidity can be sufficiently high for aluminium (which is toxic to fish) to be brought into solution.

Effects on Freshwaters

1.29. Many freshwater ecological systems are undoubtedly sensitive to acidification. Such effects were first claimed in salmon fisheries in Southern Scandinavia in the early part of the present century, and there is now extensive damage to freshwaters particularly in Norway and Canada. There is general agreement that acidification reduces the hatching rate of fish eggs, the survival of fry and the continuance of fish populations; it causes changes in the freshwater flora and fauna and so affects the food chains of the fish. In general the more valuable fish, such as trout and salmon, are more susceptible to acidity than are coarse fish.

1.30. Aluminium compounds, which may be released from certain soils subject to acidic inputs, are toxic to fish, but this toxicity is reduced if calcium ions are also present. There are strong seasonal variations in both the acidity and metal content of surface waters. Pulses of acidity occur in both the spring from snow melt and rain, and in the autumn especially after long periods of drought; such acidity pulses may be particularly damaging to fish. The correlation between acidity (or sulphate content which is sometimes used as a surrogate for acidity) of freshwaters and fishery status is neither simple nor direct.

1.31. Diatom analysis provides an important method for studying acidification of lakes over relatively long time scales, depending upon the observed relationship between the occurrence of different diatom species and lack of acidity. Such measurements may provide a definitive method for determining the effect of anthorpogenic emissions of SO_2 and NOx on freshwater acidity. Such diatom analysis of lake sediments on resistant base-poor rocks in North West Europe and North America shows that acidification has indeed occurred in the last 150 years, ie since the start of the industrial revolution. For example, the results obtained from four acid lakes in Galloway (United Kingdom) show that the beginnings of acidification varied from ca. 1840 for one lake to 1925 for another. Obviously there are significant local factors affecting the onset of acidification. Studies of the chemistry of annual layers of ice of Arctic glaciers, distant from any source of industrial emissions, show that precipitation has become distinctly more acidic at high latitudes on a circum-polar basis after about 1920.

Effects on Materials and Buildings

1.32. The corrosion and erosion of buildings and constructional materials by air pollution is a long standing environmental problem. It can be particularly severe in the cases of uncoated metals and of buildings constructed from limestone and other alkaline rocks. However, modern constructional practices—such as the use of concrete, metals, wood protectives, and antioxidants—all tend to lower the impact of air pollution. In general the effects on materials are related to air pollutant concentrations and therefore are principally a local problem. Thus anything which reduces local concentrations of air pollutants or improves dispersion will reduce building corrosion and erosion.

1.33. There is particular public concern about damage to unique historic buildings and cultural monuments which are likely to be vulnerable because of the wide use of acid sensitive materials in earlier years.

1.34. There are still, however, substantial uncertainties concerning the role of air pollutants in causing damage to materials and buildings. It is important to the development of control policies to clarify, and distinguish between, the effects of wet (sulphuric and nitric acids) and dry deposition, and of local as against long-range emissions. In turn these effects must be distinguished from the impact of carbon dioxide attack on concrete. With the exception of the latter problem, research in these areas has been limited.

Control Technologies for Acid Deposition

1.35. The main sources of pollution rising from the combustion of fossil fuels are: motor vehicles (NOx, carbon monoxide (CO), HCs and particulates), stationary combustion plant burning coal or residual fuel oil (SO_2, NOx and particulates) and stationary combustion plant burning gas oil or gas (NOx). Stationary fossil fuel combustion sources make the largest single contribution to SO_2 and NOx emissions. Many technologies to control emissions of SO_2 and NOx exist or are being developed, and these may be considered conveniently in three groups: conrtrol of SO_2 emissions, control of NOx emissions, and alternative energy sources which are low- or non-polluting.

Motor Vehicles

1.36. Motor vehicles can contribute to the production of acid compounds in the atmosphere by providing acid precursors and oxidant precursors (NOx and HCs). There is no simple relationship between the fuel burned by a motor vehicle and the emissions of NOx, CO and HCs. Emissions vary with engine parameters and driving factors, and are usually measured during a test cycle intended to simulate urban driving using a standard reference fuel. Different test cycles are employed in Japan, the United States of America and in countries using UNECE emission control specifications, reflecting the different driving conditions in each country. The use of different text cycles is justified on technical grounds, but it does lead to problems when comparing motor vehicle emissions from different countries. Most data on vehicle emissions relate to new cars and standard test cycles. Actual emissions, particularly under non-urban (that is rural and motorway) conditions, and changes through the life cycle of vehicles under typical private maintenance, are not well known, although some measurements are being made in the United Kingdom for both gasoline- and diesel-engined vehicles.

1.37. Emissions from motor vehicles can be reduced by controlling the composition of the fuel (for example, the sulphur and lead contents) or by changing vehicle design. Platinum group metals are used in the United States of America and elsewhere to catalyse the breakdown of exhaust gases. Several motor companies are developing the 'lean-burn' engine which, using higher compression ratios and lower ratio of fuel to air, attains greatly improved fuel economy and reduced emissions of CO and NOx; emissions of HCs also can be reduced by using an oxidation catalyst. There are other approaches to making fundamental changes to the internal combustion engine, which may result in reduced gaseous emissions; these are, however, at an earlier stage of development.

Control of Sulphur Dioxide Emissions

1.38. The simplest method of reducing SO_2 is to use coal or oil of low sulphur content. However, indigenous sources of coal often have to be used whatever their quality (the transport or importation of low sulphur coals may be expensive or unfeasible) whilst on a world-wide basis there is a large surplus of reserves of high sulphur crude oil. The change of feedstock can usefully reduce emissions in some countries but it is not a world-wide panacea.

1.39. In the case of hard coal, partial removal of sulphur can be achieved by cleaning processes. Maximum application of conventional coal cleaning techniques may reduce sulphur by up to 30% for high (above 2%) sulphur coals and by up to 20% for low (below 1%) sulphur coals. Advanced techniques for coal cleaning are being developed for finely ground dry coals which might be used at power stations. Super-clean coals are also being investigated for manufacturing coal-liquid slurries to displace fuel oil.

1.40. Fuel oil can be desulphurised, but at relatively high cost. However, oil companies are increasingly modifying refineries so as to increase petrol at the expense of fuel oil production. The resultant residues are difficult to desulphurise and consequently, with falling volume, it is unlikely that substantial investment aimed at the desulphurisation of fuel oil will be undertaken.

1.41. In principle SO_2 can be captured during combustion; fluidised-bed combusters to which limestone is added are potentially effective. For power stations, pressurised fluidised-bed combusters may permit the removal of up to 90% of the SO_2, without the loss of efficiency associated with the use of flue gas desulphurisation (FGD), by combining gas turbines with conventional generating plant. Alternatively the coal may be gasified, with sulphur removal, and the gas used to fire turbine generators. FGD has been demonstrated on power stations in the United States of America, Japan and the Federal Republic of Germany. Proven commercial processes are available and removal efficiencies of 90% can be achieved. Retrofitting of enough plants to have an appreciable effect on air quality is enormously expensive.

Control of Nitrogen Oxide Emissions

1.42. Several denitrification processes have been developed to remove the NOx products of combustion, either alone or simultaneously with SO_2. However, the most widely used process involves the addition of ammonia gas and its reaction with NOx over a catalyst bed to form nitrogen and water. Alternatively, and probably preferably, low NOx burners may be employed which reduce formation of NOx during combustion. Up to 40% reductions in NOx emissions can thus be achieved on new plant with low NOx burners; the greatest success has been with large burners. With catalyst beds a reduction of up to 90% is possible and retrofit is likely to be feasible.

Non-Polluting Energy Sources

1.43. The greatest scope for the displacement of fossil fuels—and the consequent reduction in the emission of pollutants which accompanies their combustion—lies with nuclear power. Thus one Pressurised Water Reactor may displace about 3M tonnes of coal a year and the associated SO_2, NOx and dust emissions. However, nuclear power has its own environmental problems, in particular the disposal of radioactive wastes, which generate their own public concern. These are considered in Technical Report 2. The question of public acceptability is one of the main constraints on the expansion of nuclear power in the Economic Summit Countries.

1.44. With the exception of hydro-electric energy, non biomass renewable energy forms are likely to provide only a small contribution to power generation in the medium term: the Organisation for Economic Co-operation and Development (OECD) estimates that they will account for 1% of primary energy by the year 2000. However, their longer term contribution to power generation in some countries, including developing countries, may well be greater. Such renewable energy sources as biomass are not necessarily pollution-free.

1.45. Although not considered further here, the importance of energy conservation should not be underestimated as another approach which can make a contribution to the reduction of polluting emissions from combustion processes.

Stratospheric Ozone Depletion

1.46. Stratospheric ozone (O_3) acts as a filter for solar ultra-violet (UV) radiation, so that any reduction in the O_3 column will result in an increased flux of UV-ß radiation, several adverse effects on human health and the environment are predicted from an increase, including higher skin cancer rates (approximately 2-4% increase of non-melanoma for every 1% depletion of total column O_3), possible supression of the human immune response, decreased productivity of some commercially important crops (food and fisheries), and degradation of materials. It is therefore important to draw attention to any actions which might cause depletion in the O_3 layer.

1.47. The natural stratospheric O_3 production/destruction cycle involves the photochemical destruction by solar radiation of both oxygen (O_2) and O_3 molecules to give (O), and (O) + O_2 respectively; the (O) then reacts with either O_2 to give O_3, or with O_3 itself to reform molecular oxygen. The result of the cycle is to provide a steady-state concentration of O_3. There are also chemical processes which destroy O_3:

$$X + O_3 \rightarrow XO + O_2$$
$$XO + O \rightarrow + O_2$$

This chain sequence (which is more complex in its details) occurs when X = H, HO, NO, Cl or Br, with NO and Cl being particularly important.

1.48. The NO is introduced into the stratosphere by diffusion of nitrous oxide (N_2O) from the troposphere (arising from the earth's surface) or from NOx emissions from aircraft flying in the stratosphere. In the presence of UV radiation the N_2O reacts with oxygen atoms to form NO which then takes part in the O_3 destroying reaction. The NO is removed from the stratosphere by oxidation first to NO_2 and then to nitric acid by the reaction:

$$OH + NO_2 \rightarrow HNO_3$$

Nitric acid is eventually transported down to the troposphere where it is removed in rain.

1.49. Reactive chlorine species are produced by the photolysis of chlorine containing compounds, particularly chlorofluorocarbons (CFCs) which have sufficiently long life to allow them to diffuse from the troposphere into the stratosphere; reactive chlorine species are removed from the stratosphere by the formation of hydrogen chloride. CFCs are an important group of industrial chemicals used as solvents in the microelectronics, refrigeration, air conditioning, plastic foam blowing and aerosol industries. Overall, the steady state concentration of O_3 in the stratosphere is governed by the occurence and rate of the various photochemical processes involving O_3, and the rate of introduction of key reactive species into the stratosphere and their removal.

1.50. Although there have been notable advances in the ability to measure stratospheric O_3 concentrations, it is uncertain whether predicted variations in O_3 concentration due to the above causes are sufficiently large now to be detectable against the variations in O_3 concentration due to nature and to other perturbing influences of man (such as the production of carbon dioxide or methane). Experimental confirmation of any change in stratospheric O_3 probably will not be possible until O_3 changes reach or exceed 2%; this is not expected to happen for at least a further 10–15 years. In the meantime it is necessary to rely on computer-based mathematical models to predict future O_3 levels and the possible effect on them of current CFC emissions. There are several types of model, some one-dimensional and some two-dimensional, the latter providing information on O_3 depletion at different latitudes. Of probably more immediate importance is the identification of the various chemical reactions involved in the destruction and/or production of O_3, and in the measurement of the relevant reaction rates. Such data form an essential input to the models. The predicted O_3 levels vary with changes in our understanding of the basic chemical processes involved. Thus recent calculations indicate an eventual reduction in the steady state O_3 concentration of 3–5%, for no growth in CFC emissions, as compared to the 16–18% predicted in 1979.

1.51. Recent work in the United States of America (8) and other countries, however, has drawn attention to the possibility that relatively rapid O_3 depletion may occur if the concentration of chlorine in the stratosphere increases from its present level of about 3 parts per billion (ppb), up to a value of about 16ppb. In the presence of nitrogen chemical entities which contain unpaired electrons (such as NO or NO_2) the free chlorine atoms become bound into compounds of limited life (such as $ClONO_2$ which overall reduce the availability of free chlorine atoms to destroy O_3. However, once total chlorine levels exceed those of the nitrogen entities, the inhibiting effect of the nitrogen entities would be swamped, and an increasingly rapid chlorine catalysed decomposition of O_3 would follow. The reaction rate of concern is being refined and validated, but the best present estimation is that it would give around a 15% reduction in the O_3 concentration. Such a depletion could occur over the next 50 years if the growth in chlorine emissions reaches 5% a year. However, the timing of this effect is believed to be modified by any changes in reaction rates and by the presence of other chemical species.

1.52. The issue of stratospheric O_3 depletion should not be confused with that of increasing O_3 in the lower atmosphere—the troposphere—which is one of the factors in the processes of photochemical smog and oxidant formation and effects.

International Collaboration

1.53. The need for accurate and comparable national inventories for SO_2, NOx and reactive HCs has been recognised by a number of international organisations. Work is at present underway in the OECD, EC, UNECE and the Executive Body of the Long Range Transboundary Air Pollution Convention. The possibility of defining a standard emission inventory suitable for use by all these organisations was discussed at an OECD meeting in Paris in 1984. OECD recently held a workshop on the compilation of emission inventories and emission factors.

1.54. The role of photoxidants, their formation, long-term transport and impact on the environment are currently being explored by the OECD Air Management Policy Group. A programme to study the long-range transport and deposition of SO_2, sulphates, NOx and nitrates across Europe is currently being undertaken by EMEP. On the basis of data supplied by member countries, EMEP (which includes all the Economic Summit Countries except Japan) produces an annual assessment of national 'exports' and 'imports' of SO_2 and sulphate. As more countries are making NOx returns it is hoped to extend this coverage to NO_2 and nitrate. Research on the chemistry of atmospheric pollution is coordinated in Western Europe by the Commission of the European Communities (CEC) under the CEC COST 611 programme.

1.55. European research on the effects of atmospheric pollution on crops and forests (including Scandinavian countries) is to be coordinated by the CEC under a new CEC COST 612 programme. A great deal of work has been done on studying the impact of acidification on freshwater biota in national programmes and in some cases through multi-lateral exchanges, for example between Canada and the Federal Republic of Germany, and the joint United Kingdom-Scandinavian rresearch programme. No general international collaborative programme has been contemplated in this area until now; this contrasts with the recent UNECE Effects Working Group meeting on forest damage. However, the UNECE Effects Working Group is now proposing to undertake an international collaborative programme to identify lakes currently undergoing acidification throughout the UNECE region, and to attempt to predict the location and number of lakes likely to become acidified in the future. The programme will call for standard methods of acidity measurement in low conductivity waters and the development of protocols for evaluating environmental damage.

1.56. The UNECE Working Group on Specific Agreement on Emission Reductions is preparing a Draft protocol on the Reduction of Sulphur Emissions or Their Transboundary Fluxes to the Convention on Long-Range Transboundary Air Pollution. This Protocol is expected to embody the commitment, already made by 20 UNECE members, to reduce their annual national sulphur emissions or their transboundary fluxes by 30% by 1993, using 1980 levels as the basis for the calculation of reductions.

1.57. The UNECE Effects Group programme also includes a survey of buildings monuments at risk with estimates of the costs of renovation; the survey includes artifacts such as stained glass, murals, paintings and fabrics. In addition the Group is concerned with developing an international collaborative programme on establishing exposure and measurement protocols for a range of buildings and structural materials. Other international initiatives in these areas include an CEC Co-ordination Group and a North Atlantic Treaty Organisation (NATO) Committee for the Challenges of Modern Society (CCMS) study concerned with the effects of atmospheric pollution on ancient monuments and methods for their protection.

1.58. Current international activity on motor vehicle emission technology is centred on the UNECE which is the principal forum within which standards for emissions are agreed in Europe and the EC. The CEC recently made a major

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study 'Evolution of Regulations—Global Approach' (ERGA) to assess the environmental need, technical potential and economic consequences of further vehicle emission controls. The OECD, at its conference on Environment and Economics 1984 (9), reviewed future vehicle emission scenarios and the potential costs of their control. In addition to these activities, the Government of Sweden hosted two meetings on the subject of vehicle emissions. The text of a declaration on the technical aspects of vehicle emission control is to be considered by participating countries in the coming months.

1.59. Experimental work on fluidised-bed combustion in power generation has been undertaken in several countries, notably under the auspicies of the International Energy Agency (IEA) at Grimethorpe (United Kingdom). Exchange of information on the technology of SO_2 and NOx emission control takes place internationally through NATO-CCMS and there have been several OECD studies relating to pollution aspects of combustion systems.

1.60. International collaboration in the fields of renewable energy sources and energy conservation takes place through the IEA, the United Nations Environment programme (UNEP) and the CEC.

1.61. There is considerable sophisticated research on the stratospheric O_3 problem, financed by governments, the CEC and industry. A Co-ordination Committee for the Ozone Layer has been set up within the framework of UNEP and there are negotiations for a global convention on the protection of the ozone layer and on a proposed protocol for cooperation in reducing worldwide CFC emissions.

Scope for Further International Collaboration

1.62. International collaboration should be encouraged on obtaining accurate and comparable national emission data, and on the forecasting of emissions, of gases which give rise to acid deposition, on a national, regional and global basis. Energy usage and fuel mix forecasts up to the year 2000 and beyond could also provide a valuable baseline on which to make decisions on long-term control strategies.

1.63. Coverage by the United Nations Economic Commission for Europe Monitoring and Evaluation of Pollutants in Europe Group (EMEP) should be extended to include data on ozone, hydrocarbons and particulate matter. Work being undertaken by EMEP and in North America on long-range transport and deposition of air pollutants should be extended to give a model covering the Northern Hemisphere, with the object of improving understanding of the source, fate and effects of the large amounts of pollutants unquantified in current models.

1.64. There should be a feasibility and design study for an international dry deposition monitoring network for aggregating dry acid deposition loadings. Such a network would develop a comprehensive picture of dry deposition loadings across the industrialised regions of the world, including deposition velocities for the range of conditions in North America, Japan and Europe. Results could increase confidence in atmospheric models and give better insights into deposition processes.

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1.65. Further collaborative research on fundamental processes that control the chemical composition and cycles of the global troposphere should include evaluating biological sources (for example, forests, grasslands and marshes), determining the global distribution of trace gases and airborne particles, investigating the wet and dry removal processes for these substances, and developing large- and small-scale models as well as instrumentation.

1.66. There is an urgent need for further international collaboration on the effects of atmospheric pollution on agricultural crops and forests. Studies are urgently needed to test the several hypotheses concerning the causes of forest damage by acid deposition (including ozone), either as a primary agent or in conjunction with other natural and anthropogenic factors.

1.67. Research in needed on methods of determining residual buffering capacities of soils and waters on local and meso- (watershed) scales.

1.68. The potential for sediment core (including diatom) analysis as a means of measuring the change of acidity of freshwater lakes with time, and the use of such information to get direct evidence of the impact of anthropogenic acidic emissions, should be explored on an international collaborative basis.

1.69. The uncertainties still surrounding understanding of the effects of air pollutants on materials, building and ancient monuments should be resolved by means of a collaborative international research programme.

1.70. There should be international collaboration on the effects on health and the environment of increased levels of UV-β radiation due to a possible decrease in strataspheric ozone.

1.71. International collaboration is needed on the control of the production and release of chlorofluorocarbons.

TABLE 1

Sulphur Dioxide Emissions from the Economic Summit Countries

Year	*Canada*	*FRG*	*France*	*Italy*	*Japan*	*United Kingdom*	*USA*
			SO_2 Emissions in M Tonnes				
1970	6.4	3.950	2.659			6.09	28.700
1971		3.800	2.966			5.83	
1972	6.3		3.493	3.200		5.64	
1973	7.037	3.928	3.703	3.169		5.80	30.126
1974	5.6	3.750	3.711			5.35	
1975		3.550	3.145			5.13	27.300
1976	5.274		3.605			4.98	26.600
1977			3.208		1.780	4.98	26.400
1978	4.5	3.550	3.385	3.3		5.02	(27.000
							(24.800
1979			3.529			5.34	25.300
1980	(4.770	3.580	3.262	3.4	1.314	4.67	(25.200
	(4.752						(26.100
1981			2.504			4.23	
1982		3.0	2.378			4.04	
1983						3.72	

Source: Reference (3)

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TABLE 2

Emissions of Nitrogen Oxides from the Economic Summit Countries

Year	*Canada*	*FRG*	*France*	*Italy*	*Japan*	*United Kingdom*	*USA*
			NOx Emissions in M Tonnes				
1970	1.4	2.450					
1971			1.170				
1972	1.5		1.248			1.728	
1973			1.346			1.854	
1974	1.6	2.70	1.312			1.76	
1975			1.256			1.70	19.6
1976	1.6	2.9				1.739	20.9
1977	1.832		1.367		1.677	1.771	21.3
1978	1.8	3.0	1.43	1.27		1.796	21.5
1979			1.481			1.893	21.5
1980	1.8		1.455		1.435	1.785	20.7
1981			1.369			1.714	
1982			1.337			1.666	

Source: Reference (3)

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TECHNICAL REPORT 2

TOXIC AND RADIOACTIVE WASTES

Introduction

2.1. The term 'hazardous waste' includes many types of waste, including those that are toxic, radioactive, explosive or corrosive. The bulk of potentially hazardous wastes arises from a wide variety of industrial processes, and the wastes themselves are correspondingly diverse. A universally acceptable and comprehensive classification has not been established because suitable common parameters are difficult to identify without reference to the circumstances in which the hazard might arise (1).

2.2. The management of hazardous wastes, whether they are toxic, radioactive or otherwise hazardous, involves a common concern to reduce the amounts of hazardous substances in the wastes, and to protect the environment and public health. For example, toxic, radioactive or corrosive chemicals may be leached from the wastes and may contaminate water resources or food chains, or may be released to the atmosphere. However, no single disposal practice would be appropriate for all categories of wastes, or even for all wastes within a particular category.

2.3. This Technical Report is concerned with those wastes which may cause pollution through toxicity or ionizing radiation. Despite the many similarities of principle in managing wastes in these two categories, most national and international bodies concerned with waste management or public health draw a firm distinction between them. For reasons of practicality, the two categories are therefore considered separately here.

Toxic Wastes

2.4. The particular properties of toxic wastes that are of concern are toxicity, corrosiveness, flammability and explosiveness. The list of potentially hazardous wastes is extensive and includes:

Acids and alkalis
Asbestos
Biocides, including pesticides
Highly reactive chemicals
Heavy metal compounds (including contaminated mine wastes)
Inorganic compounds containing halogens and sulphur
Organic compounds containing oxygen, nitrogen and sulphur
Organic halogen compounds (excluding inert polymeric materials)
Polycyclic aromatic hydrocarbons
Tarry materials and residues from industrial processes.

2.5. With appropriate management and treatment, some toxic wastes can be transformed into relatively harmless materials. Others contain immutable hazardous components and their nature cannot be changed. Their management must then ensure that the concentration in the environment, the mass-flow through food chains, and the potential accessibility are minimal and at levels which are harmful neither to public health nor to the environment.

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2.6. Uncontrolled releases from toxic wastes on a large enough scale may be such that natural processes are unable adequately to disperse and dilute toxic constituents: water resources may be rendered unpotable or unable to support life, and land may be rendered unusable for agriculture, domestic or industrial development.

2.7. If significant contamination does occur, the potential hazard is related to the properties of the waste, the routes of transport and exposure to the receiving organisms or community, the transformations along the route, the sensitivity of the receiving organisms or community, and the persistence of contaminants in the environment. Health effects on man are as various as the wastes, and range from an increased incidence of minor disorders to increased mortality and long-term effects. Few chemicals cause characteristic diseases at low levels of contamination; more commonly the effects cannot be distinguished from similar effects of other causes.

2.8. The environment itself can be affected in complex ways. Many toxic substances occur naturally at low concentrations (and in certain soils in elevated concentrations), and all species are able to tolerate a certain level of some contaminants. However, the presence in the environment of toxic substances above certain concentrations can result in various changes, ranging from alterations in species composition of a plant community to morbidity or death of plants and animals. For example, vegetation on toxic waste tips may be absent or impoverished. The reproductive systems of some animal species are impaired by toxic pollutants such as polychlorinated biphenyls and cadmium, particularly if there is bioaccummulation and if mass-flow is more important than dilution. Such effects may not be apparent immediately.

The Quantities of Toxic Waste Produced

2.9. The total quantities of wastes, contaminated with toxic substances, which are produced are large. For example, in the United Kingdom alone, some 200 million tonnes per year of contaminated aqueous material are discharged to sewers and surface waters, and out of about 50 million tonnes of solid industrial waste, about 5 million tonnes have the potential for causing damage to the environment. Mainly because of differences in definition used, estimates of the annual *per capita* production in industrialised countries of toxic wastes which have the potential directly to damage human health range widely—from 15kg to 600kg. For example, the United Kingdom produces about 1.5 million tonnes per year (30kg per person).

2.10. The trend in arisings of toxic wastes is related to the level and nature of industrial activity. The increase in arisings can however be expected to fall below a *pro rata* increase with industrial activity because of the development and exploitation of improved processes which avoid the significant cost of waste disposal, and because new high-technology industries and service industries generally give rise to smaller quantities of wastes, although these may be more complex.

Storage and Disposal Options

2.11. Wastes that arise in a large volume, such as most mining spoil, must be disposed of as they arise. It would not be practical to store such wastes for any length of time with the intention of subsequent transport and disposal.

2.12. Many toxic wastes are susceptible to treatment which changes the nature of the waste, or separates the bulk of the harmless component. Treatment options include incineration to destroy organic compounds, chemical and electrochemical oxidation of cyanides, reduction of chromium compounds, precipitation of metals from solution, neutralisation of acids and alkalis, and incorporation of toxic materials in stable solid matrices. Volume reduction is possible for some toxic wastes, and in some circumstances this can facilitate storage and disposal.

2.13. Such treatment of wastes may not only reduce the hazards of toxicity, but provide economic and environmental benefits through the potential for recycling and the recovery of valuable components. An example is the recovery of valuable metals from the growing volumes of wastes from electronic components. Hazardous components of domestic and trade wastes, such as glass and motor oils, may also be recycled.

2.14. In some circumstances storage can play an important interim role in the management of toxic wastes, allowing a sufficient accumulation for the industrial viability of metal recovery, treatment or recycling. Such processes may be preferable to immediate disposal. In a few cases interim storage may be a necessity until suitable disposal facilities are available. When wastes are stored, surveillance and monitoring are necessary.

2.15. Disposal options are distinguished by the likely duration of waste isolation that they can provide. Controlled release to the environment involves no isolation, and relies on dispersion to reduce concentrations of pollutants to acceptable levels. This must be very carefully done and rigorously monitored. A full understanding of the local conditions of the receiving environment is essential, or there will be the risk that dangerous levels of toxic substances may build up over a period of time.

2.16. Disposal near the surface in landfills can isolate some wastes until they degrade. For other wastes, not susceptible to degradation by natural processes, it can only be assumed to provide isolation from the environment for a few years, after which leaching by groundwater or disruption by excavation may occur. Large volumes can nevertheless be accommodated. The degree and duration of environmental protection achieved by this disposal option depends critically on the local geological and hydrological conditions which should be understood with respect to the type of waste to be disposed, before a site is selected and used.

2.17. Near-surface disposal, but with an engineered structure or liner to contribute to containment of the wastes, can give isolation for a hundred years or more, provided controls ensure the site is not disturbed and provided that there is rigorous monitoring of leachate during and after the operational phase. Large volumes can be accommodated by this option which is adopted for many toxic and mine wastes.

2.18. Disposal into deep oceans by sea dumping of waste relies on dispersion in a very large volume of water and sometimes takes advantage of slow release. The inaccessibility of the ocean bed provides some isolation from man's environment. However, monitoring is extremely difficult and a better understanding is required of ocean processes and dynamics before the possibility of long-term damage to the marine environment can be discounted.

2.19. Whatever disposal action is adopted, there is a need for careful management and control. Incidents of localised environmental pollution are more frequently associated with poor control of procedures than with inherent shortcomings in the disposal option or failures of engineered facilities. Any method which detoxifies the waste prior to disposal is preferable, as the long-term effects of environmentally unsound disposal cannot yet be calculated.

International Collaboration in Research and Development

2.20. The United Nations Environment Programme (UNEP) takes the lead amongst United Nations organisations for matters related to toxic waste storage and disposal. A limited budget is available for research, but the programme is more concerned with reviewing, synthesising and transmitting information from existing national research activities with a view to developing meaningful initiatives. The World Health Organisation (WHO) has commissioned some research on toxic waste disposal in the context of water supply studies.

2.21. The Organisation for Economic Co-operation and Development's (OECD) Environment Directorate has commissioned research on the management of wastes from the petro-chemical industry and on methods of incineration and treatment of wastes. Initiatives have been made concerning the usage and disposal of some toxic wastes in the OECD countries, notably for mercury and polychlorinated biphenyls.

2.22. Exchange of information has taken place in the context of the North Atlantic Treaty Organisation's Committee on the Challenges of Modern Society ((NATO-CCMS). A major study has been finished on hazardous wastes and a pilot study on the problems of contaminated land had recently been completed.

2.23. The Commission of the European Communities (CEC) commissions research on a wide range of topics. Principal areas of interest are the clearing-up of abandoned disposal sites, monitoring and optimisation of disposal facilities and the detoxification and solidification of wastes. This programme of research is now leading up to a fourth phase, although many of the results of earlier research are yet to be published and assessed (2).

2.24. The Man and the Biosphere programme (MAB) of the United Nations Educational Scientific and Cultural Organisation (UNESCO), together with the International Institute for Applied Systems Analysis (IIASA), have completed the first phase of a joint study of environmental perception and social values, based on case studies of hazardous (toxic and radioactive) waste management.

2.25. The Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU) since 1975 has been undertaking an integrated international project on biogeochemical cycles, which has examined the effect that industrial activities and biological processes modified by man (as in agriculture) have had on the movement and accumulation of chemicals in the environment. Changes in major cycles of carbon, nitrogen, phosphorus and sulpher are important to the containment and dispersal of toxic substances (3).

The Current State of Scientific Knowledge

2.26. Although the technology for safe storage of toxic wastes is well advanced, storage, other than for accummulation of economic loads for transport or treatment, is not practised to any significant extent.

2.27. Because of the length of time for which some wastes will remain hazardous, the long-term safety of disposal cannot be directly demonstrated. However, the ability to design, construct and operate disposal facilities near the surface of the ground is well established. Facilities for disposal in deeper geological formations have been designed, though few are in use. Procedures which incorporate environmental protection measures for the sea dumping of industrial wastes have also been developed, and for some there is about a decade of operational experience in their use, although there is little information on their environmental effect. For mine wastes, methods of short-term management are technically and economically established.

2.28. Safety requirements for the disposal of toxic wastes have been developed over the last decade. These embody the principle that best practicable means should be used to protect health and the environment. Evidence from past and present activities indicates that disposal systems presently used are safe when properly managed. The long-term impacts of non-degradable toxic materials at low levels of environmental contamination are far from fully understood and are the subject of continuing research.

2.29. Understanding the link between the levels of contamination in the environment and the impact on public health involves modelling the transfers of toxic substances through food chains and the assessment of other pathways by which pollutants could be inhaled or ingested. There are many gaps in our knowledge here, and assumptions have to be made about the biological effects of low levels of contamination.

2.30. Understanding of environmental effects of low levels of contamination rests on extrapolation from data on high levels at which effects are immediate and readily apparent. Acute and short-term effects are generally well understood. Possible chronic effects of low levels of contamination are less well understood, particularly for the so-called man-made toxic substances. For naturally occurring elemental toxic substances, such as mercury and cadmium, some evidence can be drawn from nature, although epidemiological studies are often inconclusive.

2.31. The areas where scientific progress is most needed are in understanding and modelling the potential transport of pollutants in groundwater and the marine environment, and in assessing potential impacts of contamination.

Although the technology for waste disposal is generally well developed, there are many areas where better technology is needed, for example the complete destruction of complex organic waste into non-toxic compounds. Recycling and waste-reduction technologies are often specific to individual industries, and need to be further studied. More need to be known of emissions from waste incinerators.

2.32. There is a need to understand better the dynamics of ocean and sea-bed processes, especially the non-steady-state processes, to assess ocean disposal options for hazardous wastes. In particular, there is a need to compare different models of ocean mixing and circulation and the natural turnover of materials. As more sophisticated models are developed, it will be important to compare results with those of previous models and to validate results against observations.

2.33. The degradation and dissipation mechanisms by which toxic substances reach the environment from disposal sites need to be better understood. There is scope for better site-specific data on geochemistry, hydrogeology and waste degradation. More information is needed on the relationship between an apparently satisfactory short-term and local impact and long-term consequences of some activities over wide areas, both on land and in the marine environment. Dispersal and bioaccumulation in food chains and long-term effects of very low levels of contamination need further study.

The Scope for Further International Collaboration

2.34. The main need is to strengthen, and make more effective, the existing international organisations and programmes. Much of the information on toxic wastes has not yet been properly assessed and reviewed, and priority should be given to support for international programmes concerned with the review and assessment of research results.

2.35. Changes in industrial activities and in the levels of non-degradable toxic substances in household wastes (such as heavy metals in batteries and 'stable' plastics) will have consequences for waste disposal practices. International collaboration on this subject is needed to anticipate situations for which remedial action could be difficult.

2.36. Research is needed on remedial action for decontaminating toxic waste sites without disturbing the materials to be treated. Such *in situ* treatment methods have the advantage that the hazardous materials do not have to be moved and handled, processes which are often associated with high cost and risks to man and the environment. Examples of where such an approach would be desirable include disused coal gas manufacturing plants and sites with quantities of asbestos.

2.37. Options for the reduction in the volume, toxicity and hazards of wastes, and for recycling and the recovery of valuable constituents, should be further investigated as a means of protecting man and the environment from the problems of very large volumes of toxic wastes, and of realising economic benefits from materials already produced.

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2.38. Comparative or cooperative studies should be made of the methods of determining the costs and benefits of various types of waste disposal, and of ensuring that the costs of waste and its management are properly assessed and paid for by those parts of industry or society that benefit from the processes which lead to the production of the waste. Such studies and assessment should include the development of cost-effective practices for site enhancement and environmental improvement.

2.39. Social studies of the public acceptability of technically viable and safe disposal options will be necessary complement to scientific research. These should assess the public perception and media presentation of apparent problem areas. Public acceptability will be vital to the continued assurance of disposal routes for some wastes. A study should be made of ways to mitigate public concern about the effect on the environment and public health from waste disposal activities. In this connection, collaboration should be maintained with the Man and the Biosphere Project 13 'Perception of Environmental Quality'.

2.40. International collaboration could ensure that the best use is made of the few opportunities that might arise for validation of models of groundwater movement and migration of pollutants, including natural analogues to disposal site behaviour. The objectives of validation exercises should be reviewed and recommendations made about the possibility of, and mechanism for, setting-up internationally funded or co-ordinated research.

2.41. Collaborative research on biological monitoring is needed to provide risk assessment data for environmental health policies and decisions. The direct measurement of chemicals in biological tissues and fluids provides actual measurements of relatonships between body burden and response that cannot be obtained in other ways.

2.42. Further attention should be given to the field of trans-media analysis of risk from toxic waste substances. Risk-based trans-media strategies offer an opportunity for pollution control agencies to provide the maximum protection from environmental risks, taken across all routes of exposure, for any given level of expenditure.

Radioactive Wastes

2.43. Radioactive wastes are readily defined and classified in terms of their radioactive emissions and half-life, and chemical and physical properties. There are differences in handling needed for wastes of high and low activity.

2.44. Radioactive wastes arise from the use of radioisotopes in hospitals and research laboratories, the use of radioactive materials in industrial processes and the defence industry, and the generation of electricity by nuclear power. The nuclear fuel cycle generates the largest quantity: from mining, nuclear reactors and fuel reprocessing. The mining of uranium results in accumulations of very large volumes of mine wastes and mill tailings—a sand-like material containing naturally-occurring, long-lived elements of low radioactivity (radium, thorium and unextracted uranium). The operator of nuclear reactors gives rise to wastes contaminated with radioactivity: materials used to remove radioactivity from cooling circuits, storage areas and ventilation systems. Reprocessing of fuel allows recovery of most of the usable radioactive energy, and over 99% of the residual radioactivity in spent fuel to be concentrated in a small volume of high-level waste, but also gives rise to other wastes containing lower levels of contamination. Spent fuel, if not reprocessed, must itself be considered as waste.

2.45. Decommissioning nuclear installations will also give rise to substantial volumes of material with a wide range of radioactive contamination, varying from the barely detectable on much of the dismantled structures to high levels on some components of the reactor containment structures and machinery.

2.46. The principal concern with radioactive waste is that exposure to increased levels of radioactivity in the environment could increase the incidence of cancers in the population. However, the types of health effect associated with low levels of radiation exposure cannot be distinguished from those which arise from other causes. Exposure to ionizing radiation may also cause a lowered resistance to diseases other than cancers. The overall effect on a population can only be investigated by a statistical analysis of the incidence of cancer and of infectious disease over time.

2.47. Radiation of natural origin pervades the environment and, for most people (and other organisms), natural radiation is the greater source of exposure. Levels of natural radiation are extremely variable and depend on factors such as altitude and local geology. All species, therefore, are able to tolerate a certain level of radiation. The sensitivity of species to radiation appears to increase with their complexity and man may be one of the most radiation-sensitive species. Therefore, measures taken to protect human health are considered generally to provide adequate protection for other species.

The Quantities of Radioactive Waste Produced

2.48. The quality of radioactive waste associated with the nuclear fuel cycle is small in comparison with the quantity of potentially hazardous waste from other industrial activities. The rate of generation is almost directly proportional to the amount of electrical power generated and to the quantity of spent fuel reprocessed. Variations exist between ore bodies and reactor types, but the generation of 1 GW(e) for one year generally gives rise to 0.1-0.5 million tonnes of mine wastes with a low concentration of radioactive minerals, about 0.1 million tonnes of uranium mill tailings, about one thousand tonnes of other low-level radioactive waste, about one hundred tonnes of intermediate-level waste requiring radiation shielding, and 30 tonnes of spent fuel or 10 tonnes of high-level waste for which heat generation is also a consideration.

2.49. In 1983 there were 243 operable nuclear reactors in the OECD area with a total installed generating capacity of 160 GW(e) contributing about one sixth of all electrical power. By 2000, the installed capacity is projected to rise to 392 GW(e) (4). The annual rate of spent fuel arising will then rise to about 10,000 tonnes. The cumulative stock of spent fuel will be about 157,000 tonnes by 2000. Other lower-level wastes will be produced in proportion.

Storage and Disposal Options

2.50. Storage of radioactive wastes can provide a supervised period during which radioactive decay can reduce the potential hazard of radionuclides with short half-lives and rate of heat generation facilitating eventual disposal. However, this involves continuing radiation exposures to operational staff.

2.51. The same considerations that apply to the disposal of toxic wastes apply to the disposal of radioactive wastes. Uranium mine wastes, mill tailings and most low-level radioactive wastes arise in large volumes and need to be disposed of as they arise. Near-surface disposal, with engineered containment, is suitable for some low-and intermediate-level radioactive wastes.

2.52. Disposal into continental geological formation can provide a very long period of isolation when groundwater movement is very slow. However, there is growing concern about the dangers of pollution of groundwaters (Technical Report 4) and there is often very little knowledge of the rate of groundwater movement or of its susceptibility to disturbance. The duration of isolation will depend on a number of barriers to the transport of leached elements, and could be many thousands of years depending on the site and depth. The volume of waste that could be accommodated is limited by economic constraints so this option may only be appropriate for some long-lived wastes. Control of the overlying surface would not normally be necessary because of the low risk of intrusion.

2.53. Disposal into continental geological formations may be appropriate for high-level and long-lived radioactive wastes. Another option, which is at an early stage of investigation, is the disposal of high-level radioactive wastes into geological formations under the deep ocean floor. It would involve similar considerations to disposal in continental geological formations, with the additional factor that sedimentation and geological processes might naturally enhance the entombment and, when containment is breached, dispersion in the ocean might provide further protection for man.

2.54. Other disposal options such as disposal into the sun or transmutation of long-lived radionuclides into non-ionizing species have been considered and are the subject of on-going research. They are not likely to be practicable options for many decades.

International Collaboration in Research and Development

2.55. The International Atomic Energy Agency (IAEA) has taken the lead amongst the United Nations organisations for matters related to radioactive waste management. The IAEA has a continuing programme on safety and regulation of radioactive waste disposal. The preparation of advice and regulations is supported by co-ordinated research programmes which promote collaboration between research institutes. Recent examples have concerned the behaviour of long-lived radionuclides released from deep ocean dumping activities, and modelling the distribution of radionuclides in shelf seas. The IAEA is also mandated by the contracting parties to the London Dumping Convention (5) to define what radioactive waste should not be dumped at sea, and to make recommendations on the basis for issuing special permits for dumping other radioactive materials. This work is supported by nationally funded research on the behaviour of radioactivity in the oceans. UNEP is consulted in IAEA activities and has recently taken an interest in radioactivity in the South Pacific, including consideration of the possible sea disposal of radioactive waste in that area. The OECD Nuclear Energy Agency (NEA) also has a role in this field.

2.56. The United Nations' Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) undertakes a continuing review of scientific information on health effects of radiation. Particular emphasis is placed on the properties and effects of the radiation. Particular emphasis is placed on the properties and effects of the radionuclides involved in, or generated by, the nuclear fuel cycle including radioactive waste management. The last comprehensive report was published in 1982.

2.57. The WHO is regularly consulted in IAEA activities and an independent review of the management of high-level radioactive waste was published in 1982. No research is currently sponsored or co-ordinated.

2.58. The NEA has sponsored numerous reviews of technical and scientific developments in the field of radioactive waste management and some policy reviews, notably on radiation protection objectives. In addition there are a number of activities sponsored by the NEA that involve arrangements for co-ordination of national research programmes.

2.59. The NEA and IAEA have jointly sponsored international symposia and reviews of the management of wastes from uranium mining and the milling and processing of uranium minerals, with the objective of developing economically practical and environmentally acceptable technologies and codes of practice (6).

2.60. The International Stripa project involves jointly funded experimental research in a disused mine in Sweden on the disposal of high-level radioactive waste in granite. Nine countries participate.

2.61. The Seabed Working Group (SWG) coordinates national research into the feasibility and safety of disposal of high-level waste into the deep ocean floor. Nine countries and the CEC are involved.

2.62. The International Sorption Information Retrieval System (ISIRS) involves compilation, comparison and review of information pertinent to the movement of radioactivity in groundwaters. Twelve countries participate.

2.63. The Co-ordinated Research and Environmental Surveillance Programme (CRESP) is concerned with research and monitoring related to sea dumping of radioactive waste in the North Atlantic. It operates in four main areas of research: modelling, physical oceanography and geochemistry, biology, and radiological surveillance (7). Eight countries participate. The scientific results are fed into the five yearly review of the site suitability in the framework of the OECD consultation and surveillance mechanism for sea dumping. A review is currently underway.

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2.64. The CEC conducts a research and development programme in almost all disciplines of radioactive waste management. These programmes are undertaken in the laboratories of the Joint Research Centre at Ispra and Karlsruhe, as well as by numerous specialised organisations and laboratories in Member States. The main subjects of research are waste storage and disposal, waste treatment and conditioning, and testing and characterisation of conditioned waste forms. Important underground experimental facilities are sponsored by the CEC programme, for example in the Federal Republic of Germany and in Belgium. Recently, two major coordinated programmes have been established: PAGIS (the assessment of safety and performance of geological isolation systems for the final storage of high-level waste in salt, clay and granite formations on land and in sediments of the deep ocean) and MIRAGE (the migration of radionuclides in the geosphere surrounding potential waste repositories).

2.65. Research also takes place in the context of international treaties and *ad hoc* bilateral and multilateral co-operation agreements. A review of the environmental impact of sea dumping of radioactive waste is being sponsored by the contracting parties to the London Dumping Convention (5), and is carried out by experts appointed by the IAEA and ICSU. The contracting parties to the Paris Convention on marine pollution from land-based sources are revising arangements to keep radioactivity releases in effluents under review, in collaboration with the NEA.

2.66. A large number of contacts, mainly at scientific levels, have been established under multi-lateral co-operation agreements. Most are concerned with exchanges of information, but some involve co-ordination of research. INTRACOIN and HYDROCOIN are computer modelling exercises, organised by the Swedish Nuclear Power Inspectorate. They compare the results of computer model predictions of radionuclide migration in groundwaters and of predictions of groundwater flows. The NEA is involved with the HYDROCOIN exercise. The United Kingdom, Japan and Australia are jointly funding research on SYNROC, a possible future matrix for immobilisation of high-level wastes.

The Current State of Scientific Knowledge

2.67. The technology for safe storage of radioactive wastes is well established. Considerable quantities of spent fuel are stored at nuclear installations and projected total storage capacities in all OECD countries more than match projected arisings, although logistic problems may occur at some installations. One technology for storage of vitrified high-level waste is being tested on a pilot industrial scale in France.

2.68. It has been suggested that the 'demonstration' of safe disposal of radioactive wastes should involve two steps (8). The first is to show that disposal facilities can be built, operated and closed safety and at acceptable cost; this may involve designing and building one or more experimental facilities. The second involves indirect demonstration of long-term safety consisting of an evaluation of the disposal systems' performance on the basis of predictive analyses confirmed by a body of technical and scientific data. Within this framework, research on the records of the natural isolation capability displayed by geological formations in the course of millions of years may represent the best tool in evaluating the reliability of the geological media as a permanent and long-lasting barrier against radionuclide migration.

2.69. For the first step, the current understanding for radioactive waste disposal has been recently summarised (9). There appears to be adequate knowledge and the ability to design, construct and operate facilities for disposal of waste near the surface. Geological disposal systems have been designed although none yet exists for radioactive wastes and there are very few for toxic wastes. Existing technology is adequate for safe excavation of shafts, cavities and vaults in many potentially suitable geological media, and for emplacement of wastes. Operating procedures which incorporate environmental protection measures for the sea dumping of industrial and solid radioactive wastes have been proposed and used. For mine wastes, including uranium mill tailings, methods of short-term management are technically proven and the costs are known. The environment can be protected while institutional control is maintained.

2.70. A generally agreed basis for an indirect demonstration of the long term safety of radioactive waste disposal now exists. Suitable predictive risk-assessment methodologies exist. The computer modelling techniques are still evolving, but the basic procedures have been demonstrated. However, these predictive methods still depend upon assumptions regarding hydrogeological pathways and the behaviour of materials over time; and they must be followed up and checked by environmental testing and monitoring. Consistent and practical radiation protection objectives exist (10), and conceptual studies have assessed the degree of confidence with which these objectives can be met using existing treatment technologies and appropriate disposal options.

2.71. Uncertainties remain in prediction of future radiological impacts. Some will always exist, for instance in predicting future land use and populations, but there is scope for improvement in the site-specific geochemical, hydrogeological and waste degradation data that are the basis of predictions. Further validation of computer models against large-scale, or extended duration, experiments is desirable.

2.72. As with toxic wastes, the areas where scientific understanding is most needed are in understanding and modelling the potential transport of pollutants in groundwater and the marine environment, and in assessing potential impacts of contamination. For individual land disposal sites, it is essential to understand the local groundwater flow system. Techniques must be further refined for monitoring and predicting movements in the areas with very low groundwater flows typical of potential disposal sites. Modelling predictions can be very uncertain and there is a need to validate results against actual observations at specific sites, each of which will have distinctive geological and hydrological characteristics. Access to sites selected for investigation is essential.

2.73. Similarly, the modelling of pollutant movements within groundwaters will need to be validated against observations. There is an abundance of laboratory data in some areas, much of it not critically reviewed, but limited data from environmental studies. large-scale, long-term experimental validation exercises or studies of natural analogs to disposal sites may both be necessary.

2.74. Thee are now extensive data on transfer factors in the main food chains for the most important radionuclides in radioactive waste. For example, the IAEA has produced a comprehensive review of concentration factors of radionuclides in fish, shellfish and seaweeds. Concentrations of radioactivity in most foods can now be estimated to within a factor of five for these radionuclides. Greater uncertainties are associated with transfers within the human body and with calculations of doses to particular organs. Estimates of the biological effects of low levels of radiation are based on extrapolation from effects observed at much higher radiation doses. This extrapolation relies on the results of basic research in radiobiology. There is very little information on the effects of low doses of radiation received at low dose rates. A linear relationship between radiation levels and the risk to health is normally assumed and represents a cautious assumption. nevertheless, research is continuing and the situation is periodically assessed by UNSCEAR and the International Commission on Radiological Protection (ICRP).

2.75. In the context of sea dumping relatively small quantities of low-level radioactive waste, a suite of mathematical models has been developed in the CKESP programme from which representative predictions can be made of the radiological impact on both man and the marine environment of dumping low-level waste. These include a model estimating the release from various packages, benthic boundary layer and ocean dispersion models estimating the physical transport of radionuclides throughout the ocean; geochemical models simulating sedimentation processes and the scavenging of radionuclides by particulate materials; and biological and dosimetry models looking at potential pathways to man and the effects on the marine biota in the vicinity of the dump site.

2.76. A great deal has already been learnt, particularly of the long-term average horizontal transport processes in the ocean, but a number of gaps in knowledge remain (7). In particular, we know little of the variations in transport, and it may be that transport is much less steady than had earlier been assumed. Safety assessments of the low-level dump site incorporate a safety factor to cover the degrees of uncertainty by making pessimistic assumptions about the values of parameters used in the models. More research is needed to refine these estimates and the associated modelling suite. For example, better estimates are needed for medium space and time scale mixing processes, vertical advection and diffusion in the ocean, the importance of chemical specification of radionuclides, and how this affects uptake into the ecosystem, scavenging, sedimentation and re-entrainment processes and deep ocean food webs.

2.77. While the understanding from scientific research will allow the acceptability of particular disposal sites to be judged, there is not yet a sound basis for optimising the number and location of storage and disposal sites for radioactive wastes. Information would be useful on the transport implications, the relative environmental impacts and the costs and benefits of regional or centralised disposal strategies. The advantages and disadvantages of using the same disposal facilities for radioactive and toxic wastes has not yet been studied in detail.

2.78. It will also be necessary to validate and substantiate models of radionuclide uptake. There are few data available on the levels of uptake of radioactivity in members of the general public, particularly in children. A number of studies have drawn attention to this deficiency and recommended research to develop methods of measuring the amount of radioactivity taken up by the human body as a result of exposures to environmental contamination as well as routine monitoring of populations near nuclear installations. Particular attention needs to be given to gut transfer factors for actinides, and effects of prolonged exposures to persistent but low levels of environmental contamination.

2.79. The uncertainty about uptake of radiactivity that a number of potential pathways be assessed. Concentrations of radioactivity along hypothetical food chains originating in the deep ocean are pertinent to assessments of ocean disposal options for radioactive waste and more information is still needed in this area.

Scope for Further International Collaboration

2.80. The main need is to strengthen, and make more effective, the existing international organisations and programmes. The general recommendations made on the scope for further international collaboration is research and development on toxic wastes also apply to radioactive wastes. In particular, there is a need for further studies on public acceptance of risk and of confidence in control and disposal schemes. There are, in addition, a number of points specific to radioactive wastes.

2.81. Encouragement should be given to the international groups concerned with asessments of ocean disposal options for radioactive wastes to increase the research on biocumulation effects in food chains originating in the deep ocean, and to organise comparisons of ocean mixing and circulation models. Validation of these should be encouraged.

2.82. Encouragement should be given to national authorities to increase the amount of data on levels of radioactivity in populations which may have been exposed to unusual levels or forms of radioactivity in the environment. This data could then be reviewed, with particular attention being given to transfer factors for actinides and other long-lived radionuclides.

2.83. An existing international scientific organisation should be asked to review available information to assess the merits of a policy of optimising the number of storage and disposal sites for radioactive wastes from the points of view of cost, environmental impact and logistical considerations. This review could be combined or co-ordinated with on-going studies by the Commission of the European Communities and a similar initiative under discussion at the Nuclear Energy Agency.

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TECHNICAL REPORT 3

MARINE POLLUTION

Introduction

3.1. The marine environment is subjected to inputs of a very wide range of pollutants, including metals and toxic chemicals from industrial processes, oil, nutrients and pesticides from agriculture, radioactive wastes, nutrients and pathogenic micro-organisms from sewage, and solid waste (such as plastic bags and soft drink cans). These pollutants reach the marine environment by many pathways: from rivers, by coastal discharge, from ships and by atmospheric deposition. There is growing concern that marine pollution is resulting in the depletion of resources which are useful to man and in harm to public health. Marine resources are of importance to industry, recreation and amenity, in addition to providing sources of food.

3.2. The marine environment is not uniform in its characteristics, in its vulnerability to environmental abuse or in its pollutant loads. Considering the oceans as a whole obscures the local or regional seriousness of ocean environment problems. Nevertheless, even in the most remote oceans contaminants can be detected which originated many thousands of kilometres away.

3.3. There is particular concern about the effects of pollutants on coastal and estuarine waters and on semi-enclosed regional seas, such as the mediterranean Sea and Hudson Bay. Not only are these areas usually more vulnerable to pollution, but there is uncertainty about the presence and effects of pollutants in, and release from, continental shelf seabed sediments. Furthermore, changes in environmental quaity in some coastal areas, while limited geographically, have a very great social and cultural importance for societies, particularly those in developing countries whose life and traditions are tied to the sea.

3.4. Most chemical elements are present naturally in marine waters. However, in the case of some non-radioactive elements (for example, cadmium, arsenic, lead, mercury and carbon), the fluxes of anthropogenic origin approach or exceed those of natural origin. Some radioelements within the marine environment are man-made (for example plutonium, americium, neptunium and curium). Many elements are distributed widely in the atmosphere, and enter the oceans via the air-sea interface, and some are spread over great distances by oceanic mixing processes, although usually over long time scales. In some cases the atmosphere is the primary source of input. Evidence exists of very widespread occurrence of certain of these substances, for example, radionuclides, lead and persistent halogenated hydrocarbons.

3.5. In recent years, there have been a number of attempts to assess the scale of the problem, the need for control or remedial action and, where damage has occurred, the likelihood of the recovery of the marine environment once action has been taken. A co-ordinated scientific approach to the assessment of the marine pollution problem has been taken by the Inter-Governmental Oceanographic Commission (IOC) (1). The most thorough and wide-ranging assessment of the state of the oceans is that undertaken recently by the Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) entitled "The Review of the Health of the Oceans" (2). This identified the needs for future action and concluded that in the open sea no significant effects on the ecosystems have been detected, and that effects of pollution have not so far been detected on a global scale. However, general trends of increasing contamination can be observed in some areas, and these should be regarded as warning signs. These warning signals are noticeable mainly in the marine areas most used by man, ie, coastal and estuarine waters and regional seas; indeed in some areas of West Africa and South East Asia fisheries have either been wiped out or become so contaminated as to render the products unsafe for human consumption. Elsewhere the role of pollution has been implicated in the decline of some marine bird and mammal populations; the number and extent of the areas affected, however, is small. Sewage is highlighted as the most common cause of pollution globally. The Review concluded that the oceans are capable of absorbing limited and controlled quantities of wastes, but that careful control of this resource is essential. Such control, however, is a major undertaking and many be beyond the present capabilities of many countries. The GESAMP Review also emphasised that the effects of pollution need to be carefully monitored and our understanding of the fate and effects of pollutants, including new substances, in the ocean must be improved.

3.6. Similar reviews, albeit less wide-ranging geographically, have been undertaken both before and since the GESAMP activity, for example under the United nations Environment programme (UNEP) Regional Seas Programmes and by the International Council for Exploration of the Sea (ICES) in the North Atlantic and Baltic Sea. A detailed appraisal of the information on the current status of the North Sea has been undertaken in connection with a Conference on the North Sea which was held in November 1984, and a review of the health of the northwest Atlantic has been prepared by the Government of Canada. Reviews of the effectiveness of international regulations, for the protection of the marine environment, have been undertaken for the Law of the Sea Conference (LOSC).

3.7. The general picture to emerge is that the most serious pollution problems affecting the marine environment concern the coastal and estuarine seas, and the largely land-locked waters. Those pollutants which cause the greatest anxiety are of high toxicity, persistence or bio-accumulation. The emphasis of concern is less on the acute short-term effects of pollutants, but on the effects of long-term exposure about which much less is known. All the reviews emphasise that pollution can be detected and should be interpreted as a sign of a situation which will deteriorate if not arrested and brought under control. They also suggest that in many areas it is impossible to state accurately the scale of an area affected or the extent of an effect, or to state what are the actual present effects of the various contaminants of concern.

3.8. The Arctic Ocean presents a distinctive and potentially serious problem of marine pollution. It receives residual pollutants from industrialised North America and Europe through transport by the Gulf Stream and North Atlantic Drift, and by long-range air transport from Europe and Western Asia. At the same time its waters are highly stratified, with much less internal mixing than in other oceans, and the persistent ice cover and low temperatures reduce photosynthesis and biological or chemical breakdown or interaction of contaminants (3). Petroleum resource development on Arctic continental shelves adds further to the potential problem. The prospect of accumulated pollution in the Arctic as a result of industrial activities in distant regions is already causing concern among those dependent upon its limited biological resources.

3.9. The need to investigate the effects of contamination of the marine environment is well recognised, and steps have been taken, both nationally and internationally, to establish a better understanding of the sources, effects and fate of contaminants. There has been a series of comprehensive research programmes, over the last 30 years, in the more developed parts of the world, to investigate the distribution and uptake of radionuclides within the water, ecosystems and sediments, and to predict their long-term fate. Steps are now being taken in the developing areas, particularly under the UNEP Regional Seas Action Plans, to investigate the more immediate problem areas (4). Work is also under way in UNEP to develop general principles for the control of marine pollution from land-based sources.

Research Collaboration

3.10. There are a number of international programmes on radioactive contamination of the marine environment, which are carried out under the auspices of several international organisations. These are not considered further here, but in Technical Report 2.

3.11. ICES has been active in the Baltic (5) and the North Seas (6) and in the North Atlantic (7). It has two working groups charged specifically with the investigation of the levels, sources and effects of pollution in the Baltic Sea and North Atlantic, and a number of specialist working groups which look at particular aspects of marine pollution, for example the effects on marine mammals, the association between pollution and fish diseases, and the use of marine sediments in pollution monitoring studies. Following two earlier and major baseline studies in 1972 and 1975/76, ICES will undertake a major survey in 1985 to establish the current levels of contamination by metals, petroleum hydrocarbons and certain chlorinated organics in fish and shellfish in the Baltic Sea, North Sea and North Atlantic, and of the levels of metals in coastal and offshore waters of countries bordering these seas. This survey will bring up-to-date the information previously available on fish and shellfish and provide for the first time a comprehensive picture of trace metals in sea water. Participants from the 17 member states will take part in a series of calibration exercises to ensure that the analytical data from each country are comparable.

3.12. The results of these investigations so far suggest that, with the exception of some coastal areas, there have been no serious problems caused directly by pollution. There is evidence that the numbers of seals in the Baltic have declined, but although pollution may be a factor, hunting and general disturbance by man is probably more important. The association of pollution and fish diseases is still uncertain, but it is clear that the relationship is complex, and that diseases occur in significant numbers of fish in areas which are not seriously contaminated. Similarly, it is apparent that there is no simple link between nutrient addition and/or presence of excessive or unusual plankton blooms. Methods of assessing trends in contaminant levels have been improved, and it is now apparent that levels of DDT and PCB are declining in the Baltic and probably also in the North Sea. However, in other areas, such as the western Arctic Ocean and the Mediterranean Sea, there is no sign of a decline. Levels of mercury are declining in all the areas which previously suffered serious contamination. This shows that recovery, even from the effects of highly persistent subsistent substances, may take place in response to remedial action or to change in industrial practice. Studies are being promoted of the effects of contaminants at other than the lethal level. These should lead to a better understanding of effects, and to controls which can be applied on the basis of more confidently derived standards.

3.13. ICES undertakes a consdierable amount of applied research in support of regulatory actions or to investigate the need for such action. A joint monitoring programme is undertaken with the emphasis on coastal waters and estuaries. At present this is directed only at mercury, cadmium and PCBs, but may be extended shortly to other substances. A major contribution by the Oslo and Paris Commissions is the collection of data on inputs of contaminants via dumping and direct discharges. As the quality of these and other data improves, it should be possible to assess, not only the sources and direct effects of the inputs, but also their fate and less direct effects. The need to consider inputs via the atmosphere has also been noted, and steps are underway to supplement existing data. Similar activities are underway in the Mediterranean, under the auspices of the Barcelona Convention and other Regional Seas organisations of UNEP. In the case of atmospheric inputs advice and assistance has been sought from GESAMP; a pilot study is underway for cadmium.

3.14. The Commission of the European Communities (CEC) promotes marine research through the Third Environment R & D Programme (1981-85). Within this programme the CEC has part-funded research on marine environmental quality, including the fate and effects of pollutants, on clean-up techniques for hydrocarbon pollution, and on biogeochemical cycles. In addition, the CEC co-ordinates nationally funded research on benthic coastal ecology (COST 47). These studies aim to establish the natural variability in species numbers and composition for selected coastal habitats as a 'baseline' against which man-induced changes (pollution effects) can be judged. Research is also co-ordinated through the CEC on the analysis and behaviour of organic micropollutants in the aquatic environment, though the emphasis is on fresh rather than marine waters. The research programme is complemented by work at the CEC's own Joint Research Centre (ISPRA) aimed at developing remote sensing techniques for the detection of marine pollution.

3.15. On a wider gographic scale the MAPMOPP Pilot Project on Marine Pollution (Petroleum) Monitoring Programme of the World Meteorological Organisation (WMO)/IOC has produced information on the incidence of marine pollution by petroleum, particularly visible surface slicks, for much of the world's sea areas. Undertaken initially to test the efficiency of the IGOSS (International Global Ocean Station System) data gathering system for marine pollution data, it has proved particularly successful, and a reasonably comprehensive and accurate picture of a petroleum pollution of surface waters has emerged. The results (8) show the surface slicks are much more likely to be encountered in particular areas (essentially those along or downwind of the major shipping lanes).

3.16. A Marine Pollution Monitoring Programme (MARPLMON) under IOC's GIPME (Global Investigation of Pollution of the Marine Environment), includes petroleum, organochlorine compounds and metals. The monitoring component of the programme is barely operational; however, considerable progress has been made on the development and testing of methods of sampling, preservation and analysis via the GEMSI (Group of Experts on Methods, Standards and Intercalibration) sub-group of GIPME. Another sub-group of GIPME, responsible for examining biological effects with a view of developing standards (GEEP-Group of Experts on the Effects of Pollution), is at present being set up.

Potential for Further International Collaboration

3.17. A considerable amount of work on marine pollution and its control continues to be done, and a number of topics are being pursued with varying degrees of activity and success. The technical co-ordination of international collaboration is satisfactory; what is needed is continued government support for the existing international organisations. Those fields of research which are least understood at present deserve the greatest measure of support and are discussed below. In the majority of these areas substantial co-ordination already exists within the International Council for the Exploration of the Sea or the Working Committee of the Global Investigation of Pollution in the Marine Environment. Continuous review and evaluation is also undertaken on behalf of the United Nations Environment Programme, the Group of Experts of Scientific Aspects of Marine Pollution and other United Nations organisations.

3.18. There should be international co-operation in identifying the threatened areas of the marine environment, specific attention being paid to the problems of semi-enclosed seas and shallow waters. Identification is needed of the centres of alleged hazard from pollution, and research on the vulnerability of these areas particularly to eutrophication.

3.19. A research priority is the assessment of the distribution, fate and scale of pollutant inputs to the marine environment. International collaboration is needed in determining the amounts and changes over time of contaminants delivered to world oceans and regional seas by various pathways (rivers, atmosphere, land, ships), through development of internationally agreed or compatible monitoring techniques (see also Technical Report 1).

3.20. Increased coordinated attention should be given to obtaining data on the long-range transport of pollutants within the ocean system, and to the processes of interaction or change on route or in residence, in order to identify areas, such as within the Arctic Ocean, where persistent pollutants may accumulate, and to assess the seriousness of the potential problem.

3.21. Remote sensing techniques have a major potential for ocean monitoring and management, for example detecting oil slicks and plankton blooms. Continued research and testing of these techniques would be greatly facilitated by international collaboration, including field studies in various ocean environments coordinated with the remote-sensed imagery to provide 'ground truth'.

3.22. Studies of the long-term impact of sub-lethal effects of contaminants, and of possible synergistic effects, on marine biota are needed, including an examination of how data from these experiments can be used to predict effects on the natural ecosystems and provide information on the assimilative capacity of marine waters.

3.23. Further studies of vertical and medium-scale horizontal physical transport processes are needed, together with a better understanding of sedimentary processes and deep ocean food webs.

3.24. A better understanding of the ecology of faecal viruses in sea water and shellfish is essential to allow proper protection of man through his consumption of shellfish and exposure to sea water during bathing and other water sports.

3.25. The provision and centralisation of standard reference materials for analytical measurements of metals and petroleum hydrocarbons in seawater, biota and sediments is a priority and would be advantageous if at an international level.

3.26. There should be coordination of national and international data gathering and monitoring programmes, and dissemination of information on marine environmental quality in forms that are useable by resource and environmental managers. The World Oceanographic Data Centres should receive continued support and should include environmental quality data and information about contaminants on a systematic basis.

3.27. There is a need for the better international exchange of data on the marine environments by marine research stations throughout the world.

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TECHNICAL REPORT 4

POLLUTION OF SOILS AND WATERS

Introduction

4.1. The pollution of soils and natural waters is a matter of growing concern not only in industrialised but also in developing nations. Chemicals introduced into the agricultural environment, or into the general environment by agricultural practices, may have adverse effects on human health, principally through food or water, or on the natural environment, for example by affecting the long-term productivity of soils and waters.

4.2. The main classes of chemicals which are hazardous in this way are fertilisers, pesticides and metals. Fertilisers and pesticides are deliberately applied to vegetation, soil and water, and have an enormously beneficial effect to secure human and animal nutrition. The use of other pesticides has also brought very great benefits of public health. Nevertheless, these chemicals can cause harm when they are present in the environment in excess quantities or under adverse conditions. Other chemicals, particularly metals, are produced as a result of industrial and other processes and may find their way to the agricultural or natural environments by a variety of pathways. As with pesticides, the hazard which they can present is often related to their high toxicity or accumulation within the soil or biota. Pollution of soils and waters by salination is considered in Technical Report 5.

4.3. Although there are hazards from the pathways of some of these chemicals to man though the air, such as following careless spraying of pesticides, the greatest concern is about the contamination of the inter-related media of soils and natural waters. These chemicals can reach the soil by a variety of pathways, including aeriel deposition, agricultural practices, decomposition of organic matter, leaching of wastes and sedimentation from waters. They can enter water either by direct means (as in spraying pesticides, some of which are specifically used for water) or by leaching from soil which acts as a reservoir for, for example, metals, nitrate or persistent pesticides. Water can transport pollutants through the environment and also permit direct ingestion by man, so the contamination of water can have more immediate or farther reaching effects than the contamination of soil. Most developed countries have extensive programmes of monitoring water which is used for human supplies.

4.4. To determine whether contaminants in soils and waters are at concentrations approaching those which are hazardous to the environment, it is necessary to monitor the concentrations in, and effects on, biota and to establish environmental quality criteria. Effects on man must be assessed by less direct means which are more difficult and provide less scientific certainty.

4.5. Trans-frontier problems may be minimal in countries such as the United Kingdom and Japan, but they can be appreciable in North America, continental Europe and elsewhere where countries share common watersheds. However, there are also indirect trans-frontier problems due to international trade in agrochemicals and waste chemicals. For these reasons the issue is one which merits international attention.

State of Scientific Knowledge

Fertilisers

4.6. Adequate mineral nutrients, particularly potassium, phosphate and nitrogen, are essential if agricultural land is to yield an optimal crop. Potassium and phosphate are normally absorbed to particles in the topsoil and create no direct environmental problems, although excess potassium in herbage induces magnesium deficiency which can affect lactating cows and ewes, and phosphate in run-off from soil, and from other sources, can be a major cause of eutrophication. However, there are certain conditions under which there may be problems associated with the use of phosphates. The solubility of phosphates is pH-dependent, and it is possible that acid precipitation may increase the release of phosphates from soil and consequently the loading in receiving waters. Extremely heavy fertilization may overburden the soil's adsorptive capacity, again resulting in heavy phosphate runoff. Heavy phosphate loadings have been shown to be detrimental to the overall health of aquatic ecosystems. An additional hazard is that most phosphate fertilisers contain cadmium, and this can give rise to the possibility of a slow build-up of cadmium in the soil.

4.7. Nitrogen is an essential plant nutrient, and is required in relatively large amounts. Unless sufficient is available, plants may become stunted and yields lower than optimal. Nitrogen is unique in its immediate and obvious effect on harvests. The main reserve of nitrogen in the soil is in the form of organic matter accumulated from plant and animal remains, both fresh and old, and from applied nitrogen fertiliser whether organic or inorganic. Well-managed soils contain up to 100 times the total nitrogen needed for one year's optimal cropping. When organic matter is broken down by soil bacteria some nitrate is released, but the amounts are usually insufficient for optimal growth of crops and therefore extra nitrogen must be applied as fertiliser.

4.8. Fertilisers usually supply nitrogen in the form of nitrate or ammonia and it is the fate and effects of nitrate about which there is concern. Studies of the effects of fertilisers on the content of nitrate in vegetables suggest that changing fertiliser input has a relatively small effect on the nitrate content of the harvested crop, and that the source of nitrogen—organic or inorganic—is irrelevant.

4.9. Concentrations of nitrates in water have been increasing in many developed countries along with the intensification of agriculture and a greater use of synthetic nitrogen fertilisers (1). Other factors, such as the rate of draw-off from aquifers and the release of sewage effluent, may contribute in particular circumstances.

4.10. Nitrate in water can cause methaemoglobinaemia (blue baby syndrome) in young infants and, for this reason, the World Health Organization (WHO) has established two levels of nitrate above which use for infant feeding should be monitored or stopped (2). At these levels other factors such as intercurrent disease or poor nutrition also contribute to the incidence of methaemoglobinaemia. It has been shown, in animals, that nitrate can be transformed to nitrosamines in the stomach and that some nitrosamines are powerful carcinogens. More recent epidemiological studies of human cancer have cast

doubt on any simple relationship between nitrate in water and the occurrence of cancer. However, there are severe inherent limitations in each of the methods at present available for detecting whether substances are harmful to humans:
in direct measurement of disease rates in populations (epidemiology), in extrapolation from experiments on animals (toxicology), and in *in vitro* systems (for example, mutagenicity). The difficulty in determining which substances contribute to the burden of disease in the general population lies more in the present state of development of basic knowledge in medical science than in failures in the conduct of applied research.

4.11. Although immediate risks are not apparent of methaemoglobinaemia or of cancer at levels of nitrate in water currently experienced in developed countries, concentrations in domestic water supplies, in certain areas and particularly in times of low rainfall, may approach the WHO limits. Furthermore, there is considerable concern about the movement of nitrate through the soil and lower levels into groundwater where it may accumulate (3). Where groundwater is used as a major source of potable water, it is important that nitrate concentrations in water should be controlled at levels below which any serious effects become apparent.

4.12. In connection with agricultural practice as a source of nitrate, past work has often assumed that much of the nitrogen fertiliser not accounted for by content of crops or incorporation in the soil reservoir is leached out in water. Recent work (4) has shown that about one sixth of the applied nitrogen can be released as gaseous nitrogen, whereas little more than a twentieth is leached into water. These studies were with a barley crop on light soil, and extension of these studies to a wider selection of soils and crops is needed.

4.13. More important are further studies of the movement of nitrate through the unsaturated zone to improve the understanding of changes in nitrate concentration in groundwater aquifers (1). Present evidence suggests that changing agricultural practice could affect aquifer nitrate levels only on a timescale of decades. Such changes would not make a rapid reduction of nitrate levels in potable water, but could be an effective method of preventing an irreversible accumulation over a period of time. In the shorter term, consideration may sometimes need to be given to other approaches such as nitrate removal or blending of different water supplies.

4.14. Eutrophication of waters is a serious problem in some areas, such as Japan, Canada and Scandinavia. Phosphates, nitrates, organic chemicals and metals are involved in the complex processes. In some curcumstances nitrogen may be a critical factor, and in Japan there is under consideration a regulation to control nitrogen, as well as phosphorus, discharges into lakes. In other circumstances nitrogen concentration does not appear to be critical and fixation by certain algae can occur. Despite uncertainties about which particular fertilisers are primarily responsible in individual cases, it is apparent that agricultural run-off is a major cause of eutrophication. In some cases phosphates from synthetic detergents are also a major cause. Experience in North America has shown that cooperative action by two countries to improve industrial and agricultural management of phosphate can have a significant effect in arresting the progressive eutrophication of a major body of water such as Lake Erie.

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Pesticides

4.15. Pesticides are synthetic or natural chemical products for the control of vertebrate pests, micro-organisms and weeds. They are widely used in agriculture, particularly for the protection of plant crops. Less attention is given here to pesticides than to fertilisers because of the generally greater attention which the former have already received. Pesticides fall into a number of different classes which show different properties and behaviour in the environment. Research into new pesticides and their mode of action is intense, and is mainly funded by commercial firms. Considerable effort is put into improving the efficiency of pesticide use; this will reduce the amount released into the environment, but not necessarily the associated hazards as smaller quantities of a more toxic chemical can have greater side effects than a large quantity of less toxic material.

4.16. The effects of pesticides within the soil environment are related to their persistence, toxicity and the range of organisms which they affect. It is notable that the newer pesticides tend to be less persistent and that many of the most persistent compounds are being phased out. However, some pesticides still remain in the soil for several years, and persistence in the soil has been shown often to be longer than laboratory studies have predicted. Althought narrow-spectrum pesticides are likely to have fewer adverse effects in the environment, there is little economic encentive for private industry to develop them.

4.17. Pesticides can have a variety of effects on communities of soil organisms. Chemicals affect different soil organisms in different ways. The stucture of the communities changes partly because of the differential toxicity of the pesticides and partly through indirect effects, for example the increase of dead plant material following application of herbicide. Some pesticides have been shown to change the structure of soil communities temporarily, while others change it on a long-term basis. Some soil micro-organisms can react by increasing the breakdown of pesticides which are applied repeatedly, thus leading to the need for higher rates of application. The long-term implications for soil fertility of pesticide usage are not well understood.

4.18. There is a potential long-term effect of pesticide residues which are bound to the soil. The extent to which adsorption prevents environmental damage, or degradation, is not always clear. It is possible that these residues are chemically changed by interaction with the soil and become more persistent. Environmental conditions also exist which can cause desorption and subsequent degradation of the residues. It is therefore necessary both to monitor the effects on the environment of the substances and to disentangle the physical and chemical reactions which they might undergo.

Metals

4.19. The main pathways of metals to soils and waters are from leaching of wastes and aerial deposition. In addition, cadmium is a common contaminant of phosphate fertilisers and of sewage sludge.

4.20. The potentially toxic metals of concern are zinc, copper, nickel, lead, cadmium and (of lesser importance) molybdenum, and mercury (5). Arsenic and fluorine, while not metals, display similar characteristics in the natural environment and are also considered here. Zinc, copper and nickel are classed as phytotoxic elements, that is they affect plant growth, whereas the remainder are zootoxic, that is they may affect human or animal health via food crops or by direct ingestion of soil. The key problem is the ingestion by animals of plants which have accumulated quantities of the metals into their edible portions. The United States Environmental Protection Agency, for example, regulates the spreading and cadmium content of sewage sludge on the basis of the degree of cadmium uptake form the soil by spinach. Toxic effects on grazing livestock are due mainly to the ingestion of metal rich soils; the eating of soil by young children is the most obvious immediate risk to human beings.

4.21. Plants need a low concentration of some elements, for example copper and molybdenum, but excessive concentrations are phytotoxic; the situation is complicated both for plants and for animals by interactions between metals, for example, zinc, molybdenum, manganese and copper.

4.22. The extent to which toxic elements are taken up by plants or leached into water systems depends on a number of factors, such as the original source, the acidity and the organic content of the soil. For example, whereas the 'total' soil concentrations of lead, zinc, flourine and arsenic in areas contaminated by mine spoil can be very high, their availability to plants is frequently lower. Much work is being done worldwide on the forms of elements in the soil (speciation) and their availability to plants. On reaching groundwaters, metals (and organic chemicals) may affect porosity and reduce the capacity of the aquifers.

Internation Collaboration

4.23. There is extensive international research collaboration on nitrates and human health, including work on gastric and othe cancers and nitrates and nitrosamines, and of the meaurement of *in vivo* production of nitrosamines and their levels in body fluids. The Commission of the European Communities (CEC), WHO, the United Nations Economic Commission for Europe (UNECE), the Organization for Economic Co-operation and Development (OECD), the Council of Europe, and the North Atlantic Treaty Organization Committe on Challenges to Modern Society (NATO-CCMS) are all involved in, or exchange information on, nitrates research, in either the planning of the research or in the assessment of the results.

4.24. The Food and Agriculture Organization (FAO) European Co-operative Network on Farm Wastes provides a valuable means of exchanging information and ideas on the effective use of farm manures, on problems of overloading soils with manure, and on odour.

4.25. A manual on field testing and control of eutrophication of slow-moving surface waters, based on experience and research in several countries, is being prepared by the Man and the Biosphere Programme (MAB) of the United Nations Educational Scientific and Cultural Organisation (UNESCO), under its study theme of the Effects on the Environment of Industrialisation and Intensification of Agriculture.

4.26. Concern about the impact of pesticides on the aquatic environment has engendered considerable international activity, both at government level and in industry. An important activity has been the formulation of detailed information requirements on the chemical, physical and biological properties of new pesticides so that a valid initial hazard assessment can be made. This has been co-ordinated by the FAO (for example, the Second Government Consultation on International Harmonisation of Pesticide Registration Requirements, 1982). Further international activity is being undertaken by the FAO European Co-operative Network on Pesticides, with Special Reference to their Impact on the Environment, Sub Network on the Effects of Pesticides in Water. The European Inland Fisheries Advisory Commission (also an FAO body) is reviewing the scientific methodology employed in Europe in assessing the hazards to aquatic life from the use of pesticides. These initiatives are aimed at improving the control of pesticides and some research programmes may emerge which require international co-operation. There has been general interest in promoting integrated pest management through demonstrations and training of farmers and operators, in order to reduce the use of pesticides. MAB has been a focus for much of this work, particularly in developing countries (6).

4.27. A report in preparation for OECD (7) has reviewed the effects of pesticides in the freshwater environment and has identified the need for research on: (a) metabolism, degradation, synergism and effects of pesticides in soil and water systems; (b) dynamics of movement of pesticides from soil to water; (c) continued monitoring of water to establish trends in pesticide residues; (d) identification of any pesticides which other studies suggest should be more closely monitored; and (e) monitoring any indication of environment effects of recently cleared pesticides. Agreed, reliable methodologies are essential, and the FAO study mentioned above will be crucial.

4.28. Much research is being undertaken worldwide on the speciation of metals in soils and their availability to plants. For example, the COST 68 action, initiated by the CEC, is concerned mainly with the use of sewage sludge in agriculture. The CEC is also studying means of reducing the input of cadmium to soils from phosphate fertilisers.

4.29. The concentration of metals in waters has attracted a great deal of effort both nationally (8) and internationally (9). The European Inland Fisheries Advisory Commission of FAO, and Canada and the United States of America through the International Joint Commission, have produced critical reviews of the literature on the effects on aquatic biota of those metals which have been shown to cause harm to such biota, including zinc, copper, cadmium, chromium, nickel and aluminium. Water quality standards proposed by the FAO Commission are used by the CEC and hence in many European countries, and are compatible with national standards produced by other countries.

Scope for Further International Collaboration

4.30. In view of the international dimension of the problems, international collaboration should be directed at harmonising methods to ensure that data on the different national situations are comparable, at facilitating the exchange of

information, and at developing agreed environmental objectives and mechanisms for the resolution of issues.

4.31. International collaboration on the effects on human health of nitrates should be strengthened, but there is scope for rationalisation of the current international activities. There is need for greater exchange of information on nitrate content in relation to differences in crop type, farming practices and geology, involving services such as those of the Commonwealth Agricultural Bureaux.

4.32. Continued international collaboration is needed in determining the substances responsible for eutrophication, their sources, and procedures for reducing inputs into threatened water systems.

4.33. A high priority for international collaboration is further research on the movement of nitrates, and other pollutants, to groundwater aquifers, and on technologies for protecting groundwater from pollution. Improved instrumentation is needed for detecting and monitoring pollution in groundwater.

4.34. Continued research is needed on the effects of different levels of fertiliser application on various crops, comparing short-term gains in productivity with possible long-term reductions in soil fertility.

4.35. There is a major need for international evaluation of existing data on pesticides to clarify effects on non-target organisms, including migratory wildlife, and to define conditions which would require additional tests to be made by the industry. Continued research is needed to develop new pesticides which have a lower toxicity to non-target organisms, and to develop further integrated forms of pest management.

4.36. Monitoring systems should be used more widely to give early warning of any significant increase in pesticide in human fats, and for research on the dynamics and persistence of polychlorinated biphenyls in the environment from old disposal sites.

4.37. Research on the bioavailability and interaction of different metals and other contaminants in aquatic ecosystems should be pursued within the framework of an international programme.

4.38. Exchange of information, and harmonisation of analytical methods, is important for metals in soils, water, sediments and biota.

4.39. International cooperation to develop more effective and agreed technologies for monitoring and reporting changes in soil and water quality should be encouraged.

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TECHNICAL REPORT 5

APPROPRIATE LAND HUSBANDRY

Introduction

5.1. The advance in agriculture and, in particular, food production has been one of the major success stories of the present century. on a global basis it has outpaced population growth, but there have been continuing failures to utilise and distribute food to the benefit of all nations. Nevertheless, despite the real achievements in agriculture, many parts of the earth suffer from poor land management and insufficient regard for the husbandry of renewable resources.

5.2. Failures of appropriate husbandry of natural resources have resulted in dereliction of land resources on a scale which has never previously affected mankind. The demand for renewable resources of food, fibre and fuel cannot be fulfilled in some parts of the world. Economic pressures have resulted in shifts in land use to produce products for exports to the detriment of sustaining local requirements. Techniques apposite to developed countries, mostly in temperate regions, have proved on many occasions to be inappropriate or directly damaging when applied in tropical regions. Gains have often been offset by the disadvantages when insufficient note of social and economic factors has been taken by the governments of the countries where these problems occur and sometimes also by the governments of countries providing aid.

5.3. The consequences of this combination of factors are desertification, aridification, deforestation, landslides and other earth movements, soil erosion and loss of fertility, with the associated human traumas. These changes threaten to reduce the effectiveness of, or in some places overwhelm, the gains in productivity that have been achieved in the recent past.

5.4. There is widespread recognition of the problems and a vast input of words, money and effort has been applied by many national and international organisations in attempts to find solutions. Comprehensive studies in many parts of the world have been undertaken by the Man and the Biosphere Programme (MAB) of the United Nations Educational Scientific and Cultural Organisation (UNESCO), the United Nations Environment Programme (UNEP) and the Food and Agriculture Organisation (FAO). A world review by UNEP, the International Union for the Conservation of Nature and Natural Resources (IUCN) and the World Wildlife Fund (WWF) identified inappropriate land husbandry as a prime problem in maintaining planetary and regional productivity and, through the World Conservation Strategy (WCS), made proposals for national and international action that have been endorsed in principle by the governments of more than thirty countries. Recently these problems were considered by the Global Possible Conference (1) where they were translated into a positive Agenda for Action in which the initiatives in science and technology are integrated into a wider plan of social and economic action.

5.5. These problems are not only the concern of developing countries or of tropical regions. At a recent Workshop of the Organisation for Economic

Co-operation and Development (OECD) (2), several reasons were given why developed countries should concern themselves with such problems. First, there are many serious cases of inappropriate land husbandry in developed countries and in all environmental zones. Many developed countries have regional development schemes that encourage more intensive use of lands of marginal productivity, and this can lead, unless great care is taken, to subsidised poor husbandry. Secondly, aid from, and trade with, developed countries is influential in both creating and helping to solve such problems in developing countries. Finally, developed countries can provide both experience and skills to assist developing countries overcome problems of land husbandry.

Characteristics of the Problem

Deforestation

5.6. The area of closed forest in the world is currently about 2,500m ha covering 20% of the land surface. The forest area in Europe, North America and the developed countries of the Pacific (1,500m ha) is changing little through concerted policies of afforestation and re-afforestation. However, reforestation schemes are most common on poor land, and the former best forests are not being replaced. In contrast the remaining 50% of the world's forest in the developing countries of latin America, Africa, Asia and the Pacific is being reduced by about 4–20m ha per year. Estimates vary considerably but the recent comprehensive FAO/UNEP assessment project indicates losses at the lower end of the range (3). Realistically, of the 1,100m ha of moist forests of the tropics, 10–20% will be permanently destroyed or severely modified by the turn of the century, with similar losses in the less well defined open dry forests.

5.7. Deforestation is primarily through expansion of agriculture to meet increasing food demands, including extension of shifting cultivation to marginal lands. Demand for selected species of wood for export and to meet increasing industrial needs may result in further losses through selective or clear felling which are not compensated for by planting or natural regeneration. These changes in forest area and composition represent losses of timber for world markets and national income, loss of essential fuelwood for rural and urban populations, and severe soil erosion, flooding and loss of fertility in some areas. In addition potentially valuable genetic stocks are lost.

5.8. There is a good general understanding of the main causes and effects of deforestation. However, the biological and architectural diversity of many tropical forests is complex, and there is a need for improved knowledge of the ecological processes within forest ecosystems to ensure efficient management of the remaining forest and its expansion. Following selective or clear felling, or burning, the rate and type of natural regeneration vary with local climate, soil conditions, vegetation cover, seed sources and subsequent management. Thus the resultant composition of the forest and its value to man are variable and, because of limited knowledge and experience, can rarely be predicted with assurance. The alternative of plantation forestry is being rapidly developed using a variety of indigenous and exotic species and genotypes, but experience is limited. In both natural and plantation forestry the largely unresolved challenge to science and technology is to select management systems which can sustain productivity and, in the case of natural regeneration, can control the composition of the forest. The requirement is to optimise growth rates and cropping regimes to the nutrient, water and biological dynamics of the forest, whilst retaining the soil fertility and structure.

Loss of Agricultural Land

5.9. Agricultural land is being lost continuously to industry, urbanisation, construction of roads, reservoirs etc, and by soil degradation. There are about 4,000m ha of arid and semi-arid lands of the world which are, or are likely to be, affected by soil degradation in one form of another, resulting in the partial or complete loss of biological production (4, 5). Degradation can be attributed to soil erosion by wind and water, to waterlogging, to the accumulation of salts and to decreased fertility because of the loss of nutrients and organic matter. The annual loss of productive land has been estimated as 3m ha by erosion, 2m ha by desertification and 2m ha by toxification. These problems are widespread. For example, large areas of the Sudan, Ethiopia, Somalia, Senegal, Brazil, Iran, Pakistan, Afghanistan and the Middle East have been lost to effective agriculture in the last decade.

5.10. Whilst many problems of erosion are undoubtedly related to climate, a basic contributory cause is reduction in vegetation cover which exposes the soil surface, reduces soil organic matter and leads to substantially increased run-off. Primary causes include over-grazing, conversion of range to arable cultivation on sensitive marginal land and removal of vegetation for fuel. Apart from the immediate loss of previously useful land through extension of deserts, the same processes are reducing the long-term production capacity of semi-arid areas.

5.11. Desertification and erosion represent terminal processes which can be reached through a network of pathways, varying in both environmental and management characteristics. For example, one major set of pathways is associated with overgrazing. Although social and economic factors control stock numbers, it is the succession of vegetation resulting from changes in grazing which is central to the understanding of desertification. The physiological, phenological and rooting characteristics of the vegetation determine its ability to withstand normal and exceptional climate conditions, maintain ground cover and control moisture. These characteristics are dependent on the species composition of the vegetation and are strongly influenced by the type and intensity of grazing and by soil conditions. Thus it is the quantitative variations in the complex dynamics of plant-herbivore-environment interactions which determine the susceptibility to, and control of, desertification and which require improved understanding. Other pathways to desertification are initiated by arable cultivation or fuel gathering, but again the environmental conditions determine the rate and type of change in soil stability.

5.12. The problems of soil toxicity are also widespread and are related, at least partly, to attempts to improve productivity through water management. Thus 0.5m ha of recently reclaimed land in Egypt are showing effects of increased salinity and waterlogging, adding to an existing 0.8m ha of traditionally farmed land already affected. Similar problems affect half the irrigated soils of the Euphrates Valley in Syria and much of the 13m ha of irrigated land in Pakistan.

5.13. In approximately 35% of tropical soils, plant growth is inhibited by some form of naturally occurring chemical toxicity, mainly from excess aluminium. Important advances in dealing with high-aluminium soils are being made in the Amazon basin. Toxicity results from a number of processes acting singly or in concert, in particular high element concentrations in soil water associated with certain parent minerals, upward movement of solutes, and concentration in surface horizons through high rates of evapotranspiration. Through artificial irrigation the hydrochemical processes are altered and under certain soil conditions toxicity may develop, in some cases through inefficient management of the irrigation system. Effects may be localised but, particularly where drainage is impeded or irrigation excessive, run-off can affect adjacent surface or groundwater systems. Additional side effects can include raising of the water table and associated waterlogging, solute movement and oxygen depletion detrimental to crop growth.

5.14. The sequence of events and interactions in the surface hydrochemistry are difficult to predict in relation to particular soil/water conditions. An additional complication is the incomplete knowledge of aquifer dynamics. Much of the water used by man today may have been within the aquifer for 20,000 years or more. Aquifers are recharged by slow drainage from the surface, combined with slow movement below ground laterally and between aquifers. The dynamics of groundwater recharge in response to varying degrees of withdrawal are particularly difficult to predict. Even with good hydrological and geological information there is uncertainty about water movement from adjacent aquifers and about changes in recharge from the surface following alterations in land use.

Land Use Interactions

5.15. Part of the failure in land husbandry results from inadequate understanding of the interactions between land uses, and of appreciation of the need for land use planning to optimise the use of land resources to meet demand. Land husbandry problems such as deforestation and desertification are too often perceived and tackled in isolation from other land uses. One fundamental interaction between uses is through hydrology. The type and intensity of land use, whether arable cultivation, irrigation, range management or forestry, influence evapotranspiration, throughfall and soil water dynamics with consequent, and often far-reaching, effects on other land uses through the amount, timing and quality of run-off and drainage.

5.16. A different type of interaction occurs when changes in one use result in changed demands on the other land. This is seen where intensification of agriculture on the more productive land types has resulted in increased fuel wood and grazing demand on more marginal land and in further pressure for deforestation. Another example is where provision, by non-integrated development projects, of water by well-digging or of fuel by afforestation attracts more people and finally hastens land degradation. Multiple land use options, such as agroforestry, have the capacity to improve supply of the material needs of local populations and can be manipulated to minimise some of the environmental hazards of more intensive management for single uses.

5.17. The effects of inappropriate land husbandry can have effects at a considerable distance or after a considerable time. For example, poor husbandry practices in stream headwaters in Nepal can eventually have serious effects downstream in Bangladesh. There is therefore a need for co-operation to ensure that long-term management economy is not destroyed by actions which are taken in ignorance of, or without due concern for, the effects on distant areas or the future.

5.18. Thus, in addition to the introduction of appropriate agricultural policies to provide incentives to farmers, there is a need to: (a) improve understanding of the quantitative interactions between uses, (b) develop options for multiple land use, and (c) develop methods and information to assist in planning the optimum distribution of land between uses, based on criteria of land potential, environmental sensitivity and demand for products.

General Factors

5.19. Pressure on the land increases as demand levels and actual populations expand. Long established, previously successful systems of land husbandry fail when the restorative capacity of the system can no longer make good the effects of increasing land pressure. New systems seek to resolve the various problems by technical means but fail if their design takes inadequate account of the environmental characteristics, the resource base or the socio-economic context.

5.20. The technical challenge is to achieve integrated management of the soil, water and biological resources appropriate to the local human situation. Failures have occurred where intensification of management has not fully recognised the interactions between component resources and the feedback effects. Short-term gains have turned into long-term losses. The variety of soil and water conditions in relatively extreme environments demands sensitive use of the existing wide variety of crop species and genotypes, in both forestry and agriculture. These principles are well known. They are fully expounded in, for example, the WCS (6), the World Soil Charter (7), the Plan of Action to Combat Desertification (PACD) (8) and the Global Possible (1). Many of the successes, although they have required sophisticated development, have been characterised by their small scale and simple application, for it is at this scale that local conditions, both environmental and social, can best be taken into account.

5.21. Sound land husbandry, in a broad sense, implies that different kinds of land are used in the most appropriate way to meet the requirements of the population. Suitable production methods as well as objectives need to be chosen. National or regional land use planning is essential. Soil mapping and land evaluation, extensively developed by FAO and others, provide critical bases for such planning and for exchanging experience (9, 10). Techniques suited to many physical environments are already well tested but their successful application remains dependent on their integration into the socio-economic context which itself is dynamically changing. Many failures in land husbandry have resulted from the introduction of methods inappropriate to local social practices or economic patterns. Improvement in land husbandry often requires greater co-operation in research from different disciplines, close contact with local conditions, and education programmes. There has also been failure by governments to carry out proper land use and agricultural pricing policies. The resulting disincentives for farmers and foresters thwart the best infusion of outside technical assistance and technology.

5.22. Assessments of the 'human carrying capacity' of land at different levels of technical input serve to underline the hazards associated with population growth and may offer a means of warning government where land husbandry failures are imminent and remedial measures urgently required. FAO is engaged in a global study of this nature and investigations with a similar objective but at village level have been undertaken, for example, in Tanzania by the Land Resources Development Centre of the United Kingdom (11, 12).

5.23. In many countries the need to survive economically forces land users to carry out practices for short-term cash profit which they are aware will damage future productivity, but they have no option. Financial and marketing systems, and government development programmes, encourage short-term maximisation of productivity, and the user who practises good long-term husbandry is penalised. Because this applies mainly to the economically developed and major food-exporting countries, it may also have important implications for the world food situation and the socioeconomic and physical survival of developing countries.

Current International Research on Key Problems

Soil Erosion

5.24. The United Nations Plan of Action to Combat Desertification (UNPACD) (8) presented extensive experience of the problems of desertification and identified the key actions required. Subsequent limitations to its success have been identified as: (a) insufficient priority given by governments faced with desertification problems; (b) gaps in understanding of integrated inter-disciplinary approaches, including socio-economic aspects; (c) inadequate transfer of knowledge to potential users; (d) lack of co-ordination and combination of effort: and (e) insufficient funding to assist anti-desertification projects. UNEP has recently adopted a World Soils Policy and Strategy.

5.25. Technology to combat soil erosion includes the maintenance of grass or cover crops on exposed ground, control of grazing, establishment of windbreaks and shelter belts, sustained input of organic matter, contour tillage and strip cropping. Research on the integration of such procedures to match local environment and socio-economic conditions is currently active, for example at the International Centre for Agricultural Research in the Dry Areas (ICARDA), and the International Crops Research Institute for Semi-Arid Tropics (ICRISAT). Whilst these centres focus on both animal and plant crop production, the integration of agriculture and forestry, with its considerable potential for provision of both food and fuel and of minimising soil degradation, is also being developed at, for example, the International Council for Research in Agroforestry (ICRAF) in Nairobi.

5.26. Analysis of the wider interrelationships between management practices and human populations has been extremely limited, although the importance of such knowledge is fully recognised both by government and by non-governmental agencies. The Integrated Project in Arid Lands (IPAL) in northern Kenya is one example, developed under the auspices of MAB and sponsored by the Federal Republic of Germany. It is centres such as ICARDA, ICRISAT, ICRAF and IPAL, located within the environment under stress, which provide essential bases for international exchange of knowledge, and its integrated development. These centres also provide a focus for the demonstration and training networks which are critical to the successful application of improved techniques.

5.27. A number of centres were established in the 1970s and their continued existence is important. The value of continuity is seen in the Central Arid Zone Research Institute, established in the late 1950s at Jodphur, India where dune stabilisation has succeeded through management of a combination of grasses and trees. Grasses can be harvested after two years and trees *(Prosopis spicigera)* from the tenth year onwards. Rotational felling can be initiated after 16 years, management showing a net profit and providing employment (13). Similarly, extensive screening of species has allowed selection of species and provenances, such as *Acacia tortilis*, with qualities of drought resistance, habitat versatility, fuel production and fast growth which are ideal for dune stabilisation programmes. A similar approach using *A. albida* is being developed by the United Nations Sudano-Sahelian Office (UNSO).

Marginal Lands and Shifting Cultivation

5.28. Extension of agriculture onto marginal lands with soils of intrinsically low fertility (oxisols and ultisols) is occuring in the arid savanna-like tropics (for example in Asia and Africa, cerrado of Brazil and the llanos of Colombia) and in the humid tropics, for example in the Amazon basin and Indonesia. The major expansion of agriculture expected during the remainder of the century must be reflected in increased areas of permanent cultivation where the aim will be to get the maximum effect by optimizing different combinations of multiple uses. The ancient systems of shifting cultivation are well understood but require conditions of land availability and population mobility which are rapidly disappearing throughout the humid tropics. The new restrictions and local concentrations of population lead to acceleration of land degradation particularly on poorer soils. For example, swidden is held responsible for an annual increase of 1–2% in the 42m ha of waste land (22% of the total area) of Indonesia (14). Successful management, particularly in the fallow phase and in fire control, can reduce dramatically the length of the cycle and provide practices intermediate between shifting and continuous cultivation. For example a 1–2 year fallow under the legume kudzu *(Pueria phaseoloides)*, a nitrogen-fixing vine from Korea, can substitute for a 25 year period of forest fallow in the Amazon basin. This, and other examples, have been developed through a Tropical Soils Research Programme in Yurimaguas, Peru, involving

North American scientists and linked to other international centres such as the Centre Internacional de Agricultura Tropical (CIAT) in Colombia (15).

5.29. The problems of management in shifting cultivation highlight the key requirements for management of marginal soils which are susceptible to degradation: maintenance of vegetative cover to conserve soil and water, and sustained nutrient capital. The nitrogen (and soil organic matter) status of infertile soils can be enhanced through manipulation of symbiotic nitrogen fixation, particularly through associations of *Rhizobium* with legumes and *Frankia* with non-legumes. There is the additional potential of enhanced phosphorus uptake where mycorrhizal species are involved, recognising that fixation of fertilizer phosphorus in soils high in iron and aluminium oxides is a major constraint to development of about 100m ha of land in acid savannas and humid tropics (16, 17).

5.30. Technical innovations of this type, as developed at the office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) and the Institute de Recherche Agronomique Tropicales et des Cultures Vivrieres (IRAT) in Senegal and major international institutes such as ICRISAT and ICARDA, are essential to improve production on marginal lands. However the understanding of the combination and interaction of crop biology with soil, nutrient and hydrological conditions is equally important. Principles of minimum cultivation, developed in traditional husbandry practices, can be usefully transferred to modern husbandry. At the International Institute of Tropical Agriculture experiments have shown that under local conditions soil loss, when virgin forest is brought into cultivation by modified traditional slash-and-burn methods, was only 1% of that from aparently more sophisticated contour banking. These experiences emphasise the need for multi-disciplinary approaches and centres such as ICRISAT and ICARDA could benefit from strengthening by, for example, soil science expertise (18).

Range Lands and Overgrazing

5.31. Soil and range degradation, leading to impoverishment of vegetation, soil erosion and loss of livestock, is widely accepted as a major problem in semi-arid regions of developing countries. Overgrazing is the central problem but the solutions, initially and ultimately, must be social. As a result, research on the methods of improvement management of grazing lands has been very limited. Although the principles of sound management are generally well understood through research in north America and Australia, definition of the potential carrying capacity of different types of rangeland in developing countries remains an important requirement for any socially acceptable stock control. While the problems of the Sahel will not be solved until numbers of domesticated animals are decreased, the apparently beneficial supply of watering points has discouraged the development of rational methods of increasing the net benefits to be gained from fewer animals. Promotion of research in range management is developing through the FAO/UNEP programme on Ecological Management of Semi-Arid Rangelands (EMASAR) and the UNESCO MAB Programme is stimulating multdisciplinary studies of IPAL in Kenya and Tunisia (13).

Soil Degradation and Water Management

5.32. Soil toxicity and other forms of degradation have minimised the beneficial effects of the major financial input to irrigation schemes—an example of development outstripping understanding even in developed countries. At the 12th Congress on Irrigation and Drainage (ICID) in 1984, the case study of the history of irrigation in the Mexicali Valley, Mexico highlighted the need for thorough feasibility and planning studies to define the scope of groundwater development before a project is implemented (19). International collaboration is usually well developed in the pursuit of major irrigation schemes because of their scale and engineering complexity, but more interdisciplinary collaboration is needed—a feature emphasised in sessions on 'difficult soils' at the same Congress.

5.33. The International Hydrology Programme (IHP), under the auspices of UNESCO and the World Meteorological Organisation (WMO), provides another important forum for dissemination of ideas and development of understanding of the processes relating climate, hydrology, ecosystems and human activity. Much of the international research collaboration is through the planning and development of irrigation schemes, often multi-national and with funding from, for example, the World Bank.

5.34. Expansion of water supplies—often an obvious development need—can exacerbate the toxicity problem. The engineering capability for large and small scale schemes undoubtedly exists but international collaboration is required to provide detailed analysis of aquifer characteristics in many parts of the world. The assessment of aquifers requires intensive geological, hydrological and engineering skills which are limited in many developing countries. The understanding of dynamics of aquifer recharge and discharge, based on theory and on the observation from existing schemes, provides a major international challenge. Investigations and planning for the supply of water should be coordinated with planning for disposal of toxic wastes (Technical Report 2). The sequence of events at the surface once irrigation has begun is still poorly understood. The hydrology in this zone is complicated by the variations in soil physical characteristics and is modified by vegetation, management and climate. These dynamics also require a thorough understanding of the chemical processes in the surface horizons to allow assessment of the irrigation effects on soil fertility.

5.35. Ameliorative practices to rehabilitate land affected by toxicity include the use of salt-tolerant plants to initiate revegetation, but control or subsequent hydrology can help in the removal of toxic elements and is critical in water table control. Fortunately some important crop plants are reasonably tolerant of high salinity and can be planted given initial reduction in toxicity, whilst fertilizers can reduce toxicity, for example of aluminium, by enhancing solute movement down the soil profile.

5.36. Continued improvement of irrigation practice is a major requirement, building on experience at many experimental stations. There is need, for example, to avoid excessive use when irrigation water is available, as this creates problems. Conservation techniques such as drip or trickle irrigation characteristically minimise the development of toxicity and reduce plant damage in areas where drainage is restricted.

Deforestation and Reforestation

5.37. Many of the causes and effects of deforestation are clearly understood. The thrusts in reforestation are designed to replenish stocks and increase supplies of commercially important species, to increase sources of wood energy for rural and urban populations, to rehabilitate areas suffering from desertification and soil degradation, to control hydrology of sensitive watersheds, to enhance agricultural production and conserve remaining forest resources. Thus there has been a marked broadening in the requirements for research and development in forestry in response to a variety of pressures.

5.38. In leading a review of international action related to tropical forestry, the FAO Committee on Forest Development in the Tropics has identified concerted efforts at various levels (20): (a) international government organisations (FAO, UNEP, UNESCO etc); (b) regional financing organisations (World Bank, International Fund for Development (IFAD), African Development Bank (ADB) etc); (c) international non-governmental organisations (ICRAF), International Union of Biological Sciences (IUBS), International Union of Forestry Research Organisations (IUFRO) etc; and (d) bilateral arrangements.

5.39. There are many small and large-scale initiatives for afforestation in tropical areas including various emergency measures, for example through UNSO. Main research requirements were identified at the IUFRO Congress in Kyoto in 1981 and efforts to co-ordinate international action to meet the research requirements are being made through IUFRO with support from the World Bank, FAO and others. Broadly, research initiatives are similar in different tropical regions and are concentrated on: (a) monitoring changes of forest resources, for example through the Global Environmental Monitoring System (GEMS); (b) national and regional planning to locate reforestation in relation to land quality and other land use requirements; (c) inventory of existing forest resources mainly to identify potential crop species; (d) screening and selection of indigenous and exotic species for particular environments and uses; and (e) management experiments and trials particularly oriented towards fuel needs, land rehabilitation, agroforestry, and plantations with reduced rotation time.

5.40. There are also initiatives in non-tropical regions. For example, the MAB Northern Network has established projects on northern birch forests and on land use and grazing, involving Nordic countries, Iceland, Canada and the United States of America.

5.41. The International Institute for Applied Systems Analysis (IIASA) is coordinating a study of the network interactions and the structure of the forestry sector at provincial, national, regional and global levels, in order to assess future developments as a basic guide to current management.

Scope for Further International Collaboration

5.42. The greatest need for further international collaboration is in evaluating how the products of science and technology can be transferred and applied more effectively to the solution of land husbandry problems, rather than to the development of new scientific understanding and tools. For example, for reforestation, the task is to select management systems which can sustain productivity and, where there is natural regeneration, control the composition on the forest. It is essential, however, that undue emphasis is not put on forms of advanced technology which may be inappropriate for the circumstances. Techniques which minimise management and put local, traditional experience into the context of scientific knowledge and the international standards of land use will be particularly valuable in future, especially on marginal lands. Within the development of technology, greater collaboration between disciplines is essential to solve existing problems and reduce the risk of future failures. Most failures have resulted from unexpected side-effects.

5.43. There are, however, areas of scientific research which would benefit from increased international collaboration. Areas of particular importance are: desertification and salination in non-tropical regions; soil stability; maintenance of fertility, especially in irrigated areas; land husbandry in areas of mixed land use; deforestation; and the effects of extreme weather or of climate change on land husbandry. The scientific background to many of these studies can usefully be related to the basic research on global change and regional dynamics coordinated under the International Geosphere-Biosphere Programme of the International Council of Scientific Unions.

5.44. There is an urgent need for a greater understanding of the social and economic aspects of the problems, and in particular on the effect of regional economic development planning on long-term land husbandry. There is room for international collaboration in a study of factors such as marketplace incentives, technology transfer mechanisms, and education and training programmes.

5.45. International organisations could play a valuable role in assessing the environmental impact, on developing countries, of foreign aid development programmes. The focus of present concern is on past failures. In the need to solve the urgent and immediate needs of many countries, international action is needed to reduce the risk of future, and even more damaging, failures. Such action should be based on the careful study of successful projects, not to copy them directly, for successful actions can rarely be transferred successfully, but to increase understanding of the ways in which foreign aid can be of both immediate and long-term environmental benefit.

5.46. Because similar problems exist in a wide range of countries, the benefit of localised research can be maximised by improved information exchange and establishment of international centres which maintain and supply material, for example potentially useful strains of micro-organisms or crop species. Research and demonstration centres within developing countries, although limited, can be successful in providing foci for research, development and training programmes, for example the existing centres of the Consultative Group on

International Agricultural Research, and recent proposals from the United Nations Environment Programme (21) and the International Union of Biological Sciences/United Nations Educational Scientific and Cultural Organisation (22). These networks of field-orientated centres increase the efficiency of transfer of techniques between countries and their translation into practice.

5.47. Support for integrated planning of land uses and management has been increasingly successful through bilateral arrangements and should be strengthened. Analsyis of trends and examination of options, whilst given low priority against immediate repair strategies to solve practical problems, are important as an essential component in longer term planning and monitoring and can be developed efficiently through international initiatives such as those of the International Institute for Applied Systems Analysis, in particular its project on the Sustainable Development of the Biosphere.

5.48. The transfer and adaptation of technology for aplication in developing countries needs to be greater than hitherto and is particularly appropriate to international collaboration. Examples are the application of remote sensing to resource monitoring and assessment as in the Global Environmental Monitoring System, the geological and hydrological survey of aquifers, the selection and manipulation of the natural genetic variation in potential crop plants, animals and micro-organisms.

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TECHNICAL REPORT 6

CLIMATIC CHANGE

introduction

Climate and Climatic Change

6.1. Climate is of fundamental importance as a major influence on human activities. It determines which parts of the earth are habitable and many of the characteristics of civilization in a particular region, such as water and energy supplies, agriculture, trade and patterns of desease. Climate change, whether natural or influenced by human activities, is therefore of major concern.

6.2. Climate is the synthesis of weather over a period, conventionally 30 years but in practice often of a shorter or longer period. The characteristics of climate are most concisely expressed in terms of their statistical properties, but may also be described usefully in terms of integrated environmental effects, such as vegetation zones. No matter what period is chosen, climate displays a degree of variability. Examples of such variations are the warming of about 0.5°C in northern hemisphere mean air temperatures during the first half of this century (Figure 1) and the period of relatively low rainfall in the Sahelian region of Africa starting in the 1960s and continuing into the 1980s. On much longer timescales (10,000–100,000 years) there is clear evidence from many sources of larger variations in mean temperature, for example between glacial and interglacial periods over much of the last million years.

6.3. The many components of the global climate system include the atmosphere (with its loading of dust and aerosols), solar radiation, the oceans, sea-ice, land ice and snow, and surface vegetation. All of these components may interact to influence the weather and therefore the climate. The degree and rapidity of response to changes is very different for the different components. Thus the temperature of a land surface may adjust to changes in the atmosphere (for example, cloud cover) within an hour or less, whereas anomalies in the ocean surface temperature may persist for several months because the mixing within a relatively deep layer of water gives the ocean a much greater thermal inertia. The seasonal warming of the tropical Pacific (El Nino) and the effects of a single anomalous event on the atmosphere (the Southern Oscillator) over more than a year have received attention recently. Perturbations of the ocean temperature at depths of 1km or so may persist for many years while for the deep ocean the corresponding timescale may be 1000 years or more. The global climate may be expected, therefore,to show variations on many timescales due solely to interactions among its components.

6.4. Other natural causes of climatic variability are volcanic eruptions and perturbations of the earths orbit. The more intense volcanic eruptions such as those of Krakatoa (1883) and El Chichon (1982) inject large quantities of aerosol in the stratosphere where they may remain in significant quantities for several years. Stratospheric aerosols reduce solar radiation reaching the ground and therefore lead to cooling of the surface and lower atmosphere. Variations in the earths orbit occur with periods of about 20,000, 40,000 and 100,000 years and longer, and these lead to variations in solar energy received.

There also are variations, apparently cyclic, in solar activity. The combined magnitude and climatic significance of these extra-terrestrial variations are unclear, but there is a possibility that they are principally responsible for the oscillations between glacial and interglacial periods. The associated energy variations on timescales of a century or less are very small.

6.5. While major changes in climate are significant only in terms of centuries or longer, the progressions are not smooth, and symptoms of the change, in terms of severe weather or ocean perturbations (as El nino), may occur suddenly, and have severe short-term economic or social effects.

6.6. Recent discussions of climatic change have been focussed increasingly on the effects of human activities. Humans affect climate principally through changes to the land surface or to the chemical composition of the atmosphere.

6.7. Solar radiation reaching the earths surface may be reflected or absorbed. Most of the energy absorbed at the earth's surface is transferred to the atmosphere either directly as heat or (following evaporation) as water vapour. Changes in the vegetative cover of the land surface can change the amount of energy available to the atmosphere or vary the fractions absorbed as heat or water vapour. The amount reflected depends on the material of which the surface is composed and also on the complexity of its structure. Thus the reflectivity of dry bare soil is mainly higher than that of a vegetated surface and forests generally absorb more solar radiation than simple structures, because radiation passing through the uppermost layer may be trapped within the canopy. On a bare soil, there tends to be less evaporation and a greater proportion of the fainfall runs off the surface. There is evidence from numerical climate models that this in turn tends to reduce rainfall. This process may will be important in such phenomena as the recurrent droughts in the Sahel.

6.8. There is considerable concern over the climatic effects of the increasing atmospheric concentration of carbon dioxide (CO_2). Measurements over the last 25 years indicate the amount of CO_2 in the atmosphere has risen steadily (Figure 2). Estimates of the concentration before regular observations began suggest that concentrations in 1860 were about 260-290 parts per million volume (ppmv) compared with the 1982 value of about 340 ppmv. This increase is attributed principally to the burning of carboniferous fuel (coal, gas, oil) which releases CO_2 into the atmosphere directly. There has also been a substantial contribution from the reduced storage of carbon in the biosphere due to deforestation and similar influences. Only about half of the CO_2 released in the burning of fossil fuels appears to have remained in the atmosphere; the remainder is believed to have been absorbed by the ocean and other minor sinks.

6.9. Raising CO_2 concentrations tends to warm the lower atmosphere and the earth's surface. It may also lead to changes in global patterns of temperature, precipitation and winds. These changes in climate could be serious for many nations and catastrophic for some, in particular through effects on agriculture and trade. For example, some parts of the earth which are at present inhabited might become unfit for human settlement, and the world's main regions of grain production might become short of water. In any case, the disruption to the world's economy would be enormous.

6.10. Another concern is that the sea-level might rise and flood very large areas of low-lying land, as a result of the melting snow and ice and the thermal expansion of the upper layer of the oceans. Some calculations, based on the CO_2-induced warming for a doubling of the concentration, have estimated a rise of a few tens of centimetres due to ocean expansion; but there are large uncertainties, particularly because it is not known to what depth the ocean warming will penetrate. If the Antarctic and Greenland ice sheets were to be melted by a change in climate, world sea level would undoubtedly rise by several tens of metres, provided that all other factors remained the same (1); but there are many uncertainties concerning the rate and possible degree of response to any given change of climate, and the net effect cannot be predicted with present knowledge. It has also been suggested that climatic warming could lead to increased precipitation, snow loading and activity of the West Antarctic ice sheet, which would then become detached from its rock base, producing a relatively sudden rise in sea-level of a few metres. Such an event, however, now appears to glaciologists highly unlikely in the next one or two centuries.

6.11. Although the most attention has been given to the effects on climate of increasing CO_2 concentration, there are other gases which are released to the atmosphere by man's activities and which may have effects on climate. In particular, increasing concentrations of trace gases such as methane and chlorofluorocarbons may have effects on climate similar to those of CO_2. Many scientists believe that the combined effects of these other gases in increasing atmospheric temperature could equal that of CO_2. The postulated effects of chlorofluorocarbons on the extent and vertical profile of the stratospheric ozone layer are considered in Technical Report 1.

6.12. There are other effects of human activities which could change the climate. These include increases in tropospheric aerosol due to agricultural 'slash and burn' practices, to the increased use of large agricultural machinery, to land degradation and large-scale fires resulting from nuclear bombing ('nuclear winter'), and the modification of Arctic sea-ice through changes in the ocean salinity resulting from diversions for hydroelectric and irrigation purposes of rivers flowing to the Arctic. At present, however, despite extensive study and preliminary modelling, the understanding of these complex processes is limited, and conclusions about the likelihood or consequences are largely conjectural. Furthermore, there is insufficient knowledge of the latitudinal or zonal distribution of atmospheric perturbations caused by human activities, and of the effect that zonal variations of atmospheric composition will have on climate.

6.13. Many of the aspects of investigating climate and climate change can be illustrated by the present research on the effects of the increasing atmospheric concentration of CO_2 which is accepted as one of the most likely causes of climatic change in the next century. Much of the work in this area (such as monitoring by satellites, research on processes in oceans, clouds and land surfaces, development of numerical models to simulate climate, palaeoclimatology, exchange of climatic data, and assessment of impacts on agriculture and on other forms of life) is necessary in any investigation of world climate and climate change. If present estimates of the effects of increasing CO_2 are correct, changes in climate from this cause should be detectable in the next few decades. Consequently much of the recent research on climate has been stimulated by the CO_2 problem. This problem presents a unique scientific challenge, in that by the time there is incontrovertible evidence of climate change it will likely be too late to halt that change. This is a prime reason why research is so important.

State of the Science

Research on Climate

6.14. Research on the climate system falls naturally into three sections: (a) estimating future concentrations of the contributing gases; (b) estimating the climatic effects due to the changes in concentrations (and to the other natural and anthropogenic influences); and (c) estimating the impact of climatic changes on conditions at the earth's surface and, in particular, on human activities.

6.15. Attempts to forecast changes in the concentration of atmospheric CO_2 over the next 100 years or so have been made in several ways. Predictions based on extrapolation of trends of the past few decades face obvious difficulties, not least of which are the paucity of stations with long-term records and the limited ability to take into account changes in use of energy. Another method is first to estimate the world's energy requirements over the next century. Since this involves accurate forecasting the state of world economy—an almost impossible task—it also leads to great uncertainties in the prediction of future CO_2 concentrations. Given the future energy demand, the fraction supplied by fossil fuels is postulated and the resulting concentration of atmospheric CO_2 is usually estimated by assuming that a fixed concentration remains airborne. However, as living organisms both absorb and release CO_2, this may be too simple an approach and, alternatively, one can attempt to predict the uptake of CO_2 by the oceans and the biosphere in detail. This approach also leads to problems because of uncertainties of both the processes and quantities. Given the large uncertainties in the projected use of fossil fuels and the possible inaccuracies in the partition of the resulting CO_2 between the atmosphere and other sinks, it is not surprising that there is a wide range of concentrations predicted for future atmospheric CO_2. Predictions of the date at which CO_2 concentrations will reach 600 ppmv (just over a doubling of the estimated pre-industrial level) have varied considerably, with the most recent suggesting some time in the third quarter of the next century.

6.16. The lack of data has not yet allowed equivalent predictions for the other gases which may have effects similar to CO_2.

6.17. Before discussing the response of climate to CO_2 (and other perturbations), it is helpful to consider the earth's heat balance. The earth receives energy in the form of short-wave radiation from the sun, some of which is reflected back to space by clouds or the surface, or is absorbed directly by the atmosphere (Figure 3). The remainder is absorbed by the surface and is transferred to the atmosphere by conduction, radiation or released latent heat. Clouds, CO_2, ozone, water vapour and other atmospheric trace gases absorb and emit long-wave radiation. They absorb or 'trap' much of the radiation from the earth's surface, re-emitting both upwards to space, and back downwards to the surface. As a result, the earth's surface is some 20°C warmer than it would be without an atmosphere, a phenomenon popularly known as the 'greenhouse effect'.

6.18. The direct effect of increasing CO_2, or other trace gases, is to enhance the greenhouse effect, warming both the atmosphere and surface. Doubling CO_2 concentrations from 300 to 600 ppmv would raise the temperature of the lower atmosphere and surface by about 1°C due to radiative changes alone. The warming would allow the atmosphere to hold more water vapour, itself a 'greenhouse' gas which, in the case of doubling CO_2, might increase the warming to about 2°C. Changes in atmospheric heating would give rise to changes in the atmospheric circulation and the patterns of temperature, cloudiness and precipitation which in turn would lead to changes in conditions at the earth's surface, including snow and sea ice, and eventually the circulation of the oceans (Figure 4). All of these might enhance or diminish the initial response to the perturbation. There are two methods by which we can study these complex interactions: by looking for analogues of warmer or colder climates in the earth's past, and by using three-dimensional numerical models of climate.

6.19. It is known that atmospheric CO_2 levels have varied in the past. Data from ice cores indicate that the values fell to about 200 ppmv during the last ice age which reached a maximum about 18,000 years bp (before present). Present evidence suggests that the reduction in CO_2 levels may have enhanced the severity of the ice age but is unlikely to have initiated it. The most recent analogue of past warm climates is the mid Holocene (8,000-4,000 years bp), which probably was not more than 1.5°C warmer than present and for which changes in precipitation and temperature have been approximately determined. For example, the Sahara is known to have been wetter during this period. The usefulness of analogues from past climates is limited by the uncertainties in determining the climate from proxy data, and the possibility that more than one factor may have been responsible for the changes in climate.

6.20. Numerical models of climate have been developed from atmospheric general circulation models. In a numerical model of the atmosphere values of temperature, humidity and wind are stored at points on a horizontal grid, typically 200 to 500 km apart, at several levels in the atmosphere. These values are allowed to evolve in time by solving the equations of motion and thermodynamics at each point. Many of the physical processes such as radiation, precipitation and the exchange of momentum, heat and moisture at the surface have to be represented statistically ('paramaterizations') using observations made in the real atmosphere or the laboratory, or numerical experiments with more detailed mathematical models. Once certain boundary conditions, including the distribution of sea surface temperatures and sea ice, orography and the time of year have been prescribed, the atmospheric model can be stepped forward in time over the period of interest, which may be a month or more.

6.21. The quality of the simulation may be assessed by comparing the model data with climatological data for the relevant time of year. A more stringent test is to proceed through one or more annual cycles, to ensure that the parameterizations are valid over a range of climatic regimes. This is particularly useful if the model is to be used to assess changes in climate which are relatively small compared with the changes in the seasonal cycle. Present models simulate the large scale features of the observed circulation well but regional details are often inaccurate.

6.22. A climate model should include all the elements of climate appropriate for the timescale of interest (Figure 4). Thus, clouds, the land surface and snow cover, sea ice cover and the ocean must all be taken into account if climate change over several decades is being considered. Three-dimensional models analogous to those used for the atmosphere have been developed to simulate the circulation of the oceans. However, to date, studies of the global effect of CO_2 concentrations have not been able to incorporate the changes in the oceans realistically. For reasons of complexity and extent of the computations involved, models cannot go beyond a certain degree of detail in simulating the physical and chemical processes. Furthermore, some scientists believe that the deterministic approach to prediction may have intrinsic limitations.

6.23. Experiments to date have used atmospheric models with prescribed sea surface temperatures or a highly simplified but interactive representation of the oceans. Simulations with and without the appropriate CO_2 perturbation are run to obtain the equilibrium climates and the differences between them are studied. In order to obtain changes which can be distinguished above the inherent variability of the simulated climate, the perturbations applied are often exaggerated. These experiments are useful to indicate the sensitivity of climate to certain types of perturbations. Latest results suggest at least a global mean surface warming due to doubling CO_2 of 1.5-4.5°C, with much of the enhancement due to the reduction in highly reflective snow and sea ice cover and changes in cloudiness. These simulations produce a surface warming which in winter is most pronounced in high latitudes, and least in the tropics, a general reduction in sea ice and snow cover, an increase in run-off in high latitudes and, in most cases, a drying of the land surface in northern mid-latitudes in summer. Although the large scale changes are generally consistent from model to model, there is little agreement on the regional details.

6.24. In reality, perturbing factors would probably change gradually and the evolution of the climate response with time becomes important. For example, the concentration of atmospheric CO_2 has increased by 8% since 1958, which on the basis of recent model estimates would be expected to produce an equilibrium increase of about 0.2-0.45°C in global mean temperature. Such an increase is not evident in the recent instrumental record (Figure 1), possibly because of temperature variations of similar magnitude which may be due to other causes. Furthermore, one might expect any atmospheric warming to be delayed by the large thermal inertia of the oceans. This depends critically on the rate at which heat is mixed downwards in the deep ocean (and is closely related to the problem of determining the rate at which CO_2 is absorbed by the oceans). Results from idealised coupled ocean-atmosphere models and calculations using simpler models suggest that the ocean may slow the response of the atmosphere. As a consequence, much of the response of climate to the estimated 30% increase in atmospheric CO_2 since about 1860 may not yet be apparent.

6.25. It has been argued that the thermal inertia of the ocean will vary with latitude so that the response of climate to gradually changing perturbations may differ substantially from that found in equilibrium. Should this be the case, one will need to know the evolution of the perturbing influence with time and use it in a fully coupled dynamical model of the ocean and atmosphere in order to forecast changes in climate.

6.26. The world climate is not homogeneous. There are regional and latitudinal-zonal variations of climate, of CO_2 concentration and of other relevant variables. These factors are of great importance in determining the response of climate to increases in CO_2 and other atmospheric gases.

6.27. An increased atmospheric concentration of CO_2 may also have a direct economic impact by, for example, enhancing the growth or increasing the resistance to drought of some crop plants.

6.28. The predicted changes in climate accompanying increases in atmospheric concentrations of CO_2 and other gases will have widespread and possibly catastrophic impacts on agriculture, energy supply and demand, sea-defences, etc. Until reliable predictions of regional climates are available, evaluation of the impact of climate change will be on a generalised level. However, by specifying scenarios, or using the estimated results from present climate models, predictions of the likely magnitude of impacts have been made and the methodology for assessing the impact is being developed. Even if the changes in climate were known exactly, there would, for example, be considerable uncertainty in determining the precise effects on agriculture, given the present shortcomings in the state of modelling crop growth.

Research on Aerosols

6.29. Aerosols are released to the atmosphere from many processes, including industrial activity, land clearing and machine-tillage agriculture. The effect of aerosols on climate depends on a number of factors, including the distribution of particle sizes and their optical properties, their concentrations and their vertical and horizontal distribution. Attempts have been made to quantify the relative contribution of past volcanic eruptions to the loading of stratospheric aerosols. These studies have been useful in indicating the three-dimensional spread and distribution of aerosols from a single point source, and the residence time in the atmosphere of particles of different sizes; however they are insufficient to allow, for example, detailed calculations of the associated radiative perturbations and hence their effect on climate.

Changes in Surface Vegetation

6.30. The extent of changes in vegetation has been gauged from past records of land use and, in recent years, from satellite data. Experiments with numerical models indicate that climate is sensitive locally to changes in land surface properties, though the imposed changes have been larger than those observed.

Areas of Uncertainty: Research Needs

Assessment of Perturbing Influences

6.31. There is a need for improved monitoring of factors known, or likely, to perturb climate including changes in land use and surface properties, the concentration of trace gases and aerosol loading. Further information is required on the formation, distribution and radiative properties of aerosols so that their effect may be incorporated faithfully in climate models. In order to account for the effect of recent increases in CO_2, a more accurate determination of the role of the biosphere and the rate at which CO_2 and other trace gases are mixed down into the deep ocean are needed.

Climate Effects

6.32. Many of the processes affecting climate are poorly understood and are represented inadequately in models, including the hydrology of the land surface and the effects of vegetation, clouds, snow and sea ice cover and the ocean circulation. Further studies are needed before reliable parameterisations can be introduced in large-scale models. There is a requirement for continuing observational data on which to base and test numerical models. At present many data, particularly over the ocean, are limited to specific regions or limited periods, and may be unrepresentative. Thus there is a need for regular global monitoring of certain quantities, for example sea surface temperatures and sea ice extents, as well as more intensive data gathering during events of particular interest. Regular long term monitoring of climate variables is also a prerequisite for determining the inherent variability of climate and detecting climate change.

6.33. Further refinement of numerical climate models is essential to improve the simulation of regional climate which at present is inadequate for most impact studies. There is much to be done in the interpretation of model data and comparison with observations. The effort to understand the model results, in terms of the physical processes represented and of the discrepancies in results from different climate models, should be intensified.

6.34. There is an urgent requirement for a careful and comprehensive estimate of the scale and rate of response of climate to the increase in CO_2 (and other trace gases), and to other anthropogenic perturbations, over the last few decades and the projected increase in the near future so that the model predictions can be verified against observed data. This will also require the isolation of changes due to factors other than trace gases.

Impacts

6.35. Research on the evaluation of impacts is of great importance, but is heavily dependent on more reliable predictions of regional changes in both mean and extremes of climate. Nevertheless, there is scope now for developing methods to use when improved forecasts become available. There is also considerable uncertainty on the effects of changes in temperature, precipitation and atmospheric CO_2 on agriculture and a need to extend present research over a wider variety of plants and habitats. Research on non-agricultural aspects, including flood forecasting and winter weather analysis is also needed. Finally, attention should be given to the overall effects on world economics and trade of all these aspects.

International Collaboration

Organisation of Research

6.36. The problem of the increasing concentrations of CO_2 and other trace gases in the atmosphere illustrates the global nature of both the cause and effect of changes in climate. Climate research involves many disciplines and the resources required are generally beyond the means of any one nation. A framework for international co-operation is provided by the World Climate Programme (WCP). This involves several international agencies such as the World Meteorological Organisation (WMO), the International Council of Scientific Unions (ICSU) and the United Nations Environment Programme (UNEP). The WCP represents an attempt to produce a co-ordinated programme of research to understand climate and climate change and their impacts, to identify weaknesses and shortcomings in that programme, to exchange information on existing climate data and to emphasise priorities. The WCP operates not by the direct funding of research, but by encouraging international co-operation and the exchange of scientific information through meetings and conferences. Most research is funded nationally and many countries have their own national climate programmes which contribute to the WCP. Because of the large computing resources required, detailed numerical modelling of climate is largely confined to government laboratories; other research may be carried out by government laboratories, universities or, in some cases, private industry.

6.37. The Commission of the European Communities (CEC) funds research in Member States through its climatology programme; much of this work is directed towards the needs of the European Communities (EC). The international space research programmes contribute to climate research by their climate satellites which observe the atmosphere, land surfaces and oceans.

Potential for Further International Collaboration

6.38. The activities of the World Climate Programme, the programmes of the Commission of the European Communities and the programmes of satellite measurements should be supported so that individual nations can match their own expertise with the particular needs of the research programme, rather than fragment available resources on a wide range of problems. Further bilateral cooperation between countries having national climate programmes would also provide a useful mechanism for advancing climate research and services (such as experimental climate forecast studies).

6.39. A high priority in climate research is to increase precision, accuracy, resolution and coverage of climate observations. These involve ground, ship and satellite observations, in addition to routine determinations of basic quantities.

Satellite observations, in particular, provide a unique capability for the global monitoring of climate. Meteorological satellites provide global data on the earth's radiation balance, the distributions of atmospheric temperature, humidity and clouds, and land, sea and ice surface temperatures. Land satellites monitor changes in land surface properties, and ocean satellites provide data on ocean currents, ocean surface winds and ice coverage. The Technology Growth and Employment Working Group's area for collaboration on Remote Sensing from Space has endorsed the recommendation by the International Union of Geodesy and Geophysics and the International Council of Scientific Unions that the existing and future satellites of the United States of America, the USSR and the European Space Agency obtain, on a continuing basis, laser- and radar-altimeter profiles of the surface of the Antarctic and Greenland icecaps. Changes in the surface elevation of ice caps, measurable with equipment now available, should give a signal of global response to climate change that is more sensitive and significant than any other planetary-scale indicator known.

6.40. Advances in climate prediction require improvement of climate models and the development of reliable forecasting techniques of climate variables, primarily temperature and precipitation, at least on one- to three-month timescales. Two key elements for urgent attention are the role of clouds in the earth's radiation balance and the role of oceans in near- and long-term climate. Both processes will require years of study by the scientific community, ideally within the World Climate Programme framework, and particularly by countries with the necessary computer capability. In this context support should be given to three new international collaborative projects: the International Satellite Cloud Climatology Programme (under the World Climate Programme), the Tropical Oceans Global Atmospheric Project and the World Oceans Circulation Experiment.

6.41. One of the objectives of the World Climate Programme is to warn governemnts of forthcoming climate changes which may significantly affect human activities. International bodies involved in the World Climate Programme also have an important role in making governments and nations aware of the consequences and risks of these change, in particular the potential economic impacts.

6.42. Co-operation between the different disciplines involved in various aspects of the problem should be encouraged so that each is aware of what is required and what can (or cannot) be provided. For example, the determination of the effect of increased carbon dioxide involves palaeoclimatolgy, glaciology, biology, chemistry, meteorology, oceanography, agriculture, economics, etc. Ways should be found for the present climate programmes to involve specialists in these disciplines to a greater extent.

6.43. Cooperation should be encouraged between climate modellers and the modelling studies of future food production on a global and regional basis, by the Food and Agriculture Organisation, to ensure that factors of climatic variation are taken into account in predictions or scenarios of world food production.

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6.44. The exchange of scientists, the exchange of data and information, and the comparison of results between different countries should be encouraged to foster the development of new ideas and to extend the use of the available data. Data should be gathered, whenever possible, in common formats and in central locations where the data can be made available at reasonable cost to research scientists. The three World Climate Data Centres should be continued and strengthened.

6.45. Given that the importance of a full understanding of climate change and its impact is essential to the well-being of all nations, it is necessary to accept that the achievement of this degree of understanding requires the commitment of significant resources for a long period of time for the necessary progress to be made. National research programmes contributing to the World Climate Programme should be accorded a high degree of priority and continuity in the allocation of national funds over the next decade. There is also room for further European cooperation within the framework of the European Communities.

Figure 1 — Changes in surface air temperature, 1880-1980 (Reference 2) (Copyright 1981 by the American Association for the Advancement of Science)
Figure 2 — Changes in concentration of atmospheric CO_2 (parts per million) at Mauna Loa, Hawaii, 1958-82 (Reference 3)

Figure 3 — Heat balance of the atmosphere (Reference 4)
Figure 4 — Physical processes and properties that govern global climate and its changes (Reference 4)

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