INSTITUTE OF TERRESTRIAL ECOLOGY
(NATURAL ENVIRONMENT RESEARCH COUNCIL)
Report to Department of the Environment

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Recommendations for a UK National Strategy for Research on the Potential Impacts of Ozone Depletion

Report of a 2-day Workshop, Peterborough, UK, 27-29 January 1997.

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EXECUTIVE SUMMARY

- The conclusions of the First Report of the UV-B Measurement and Impacts Review Group (UMIRG) and other international assessments of the impacts of stratospheric ozone depletion were considered at a 2-day scientific Workshop by 36 representatives of government departments, research bodies and scientists in order to identify and recommend prioritised requirements for further research on UV-B impacts. Research and monitoring programmes on ozone depletion science were not considered within the scope of the Workshop. This Report is a compilation of the views of the individuals present. It does not necessarily represent the priorities and strategy of the organisations represented at the Workshop.

- There remain gaps in our knowledge and limitations in our ability to predict changes in stratospheric ozone and the impacts of increased UV-B on certain aspects of human health, ecosystems, materials, air quality and socio-economic factors.

- Further research on the science of ozone depletion and its impacts is needed to address these limitations in order to:
  - underpin mitigation efforts and provide a rationale for long term protection of the ozone layer.
  - cope with existing and projected ozone depletion, to identify important effects and to develop response strategies.

- Three Working Groups considered the current knowledge and understanding of the risks of ozone depletion and increased UV-B and established priority areas for further research and development for consideration by research councils, government departments and funding agencies when formulating their own research strategies.

RESEARCH RECOMMENDATIONS

UV-B monitoring

- It is essential to establish constructive methods of communication between researchers and the beneficiaries of research including contributions to public awareness. Coordination of UV-B research with other national research activities on climate change, photochemical oxidants and stratospheric ozone, as well as maintaining links with and participating in international programmes, are essential for the scientific support of decisions on policy issues.

- The current UK network of monitoring of UV-B is just adequate to provide information at a national scale and must be maintained. It is highly desirable to improve measurement instruments and capabilities and this may provide commercial opportunities. It is essential to compare monitoring instruments and calibration standards within the UK with international networks in order to ensure accuracy of information.

- Improvement of the UK capability to model spatial and temporal variations in UV-B levels is needed to enhance the accuracy of predictions of impacts on materials,

ecosystems, human and animal health and socio-economic factors. This would also enhance the accuracy of interpolating UV-B exposures between monitoring sites.

- The ability to detect UV-B impacts on ecosystems would be greatly enhanced by site specific monitoring of UV-B at field sites of environmental change research.

Materials

- Increases in UV-B will have a detrimental impact on certain materials and these should be quantified in relation to their spatial distribution and exposure to UV-B and in order to establish thresholds for damage in relation to other environmental factors such as temperature and air pollution.

Air Quality

- An increase in UV-B levels will lead to some increase in ground level ozone concentrations which in turn have impacts and it is important that this and other secondary impacts of stratospheric ozone depletion are quantified.

Terrestrial and Aquatic Ecosystems

- There are currently considerable uncertainties about the nature and degree of UV-B impacts in both terrestrial and aquatic ecosystems although some broad knowledge of crop sensitivities has been determined. It is not currently possible to identify key ecosystems or species that are vulnerable. Consequently, it is essential to determine the range of variability of sensitivity in natural ecosystems in order to identify key targets for protection and monitoring. Knowledge of the physiological basis for sensitivity or tolerance and the influence of genetic effects of UV-B on mortality and fecundity would assist with identification of adaptive strategies.

- Future ecosystem impacts research should be undertaken using appropriate action spectra (which define wavelength sensitivity) and using the best available methodologies for long-term studies with appropriate UV-B doses and realistic environmental conditions. A desk study evaluation of the sensitivity of predicted impacts to the nature of action spectra and dose-responses and the determination of action spectra for key ecosystem components under field conditions are required to ensure the accuracy of predicted impacts.

- Biogeochemical cycles are responsible for the availability of nutrients in ecosystems and the fluxes of certain greenhouse and chemically important trace gases to the atmosphere. Together with ozone and UV-B, biogeochemical cycles were identified as two of the four priority areas for systemic research in the UK Global Environmental Research Strategy. There is limited knowledge of impacts on biogeochemical cycles in terrestrial ecosystems. The reported effects of UV-B in marine ecosystems, including effects on the degradation of dissolved organic matter, sulphur cycles and the bioavailability of trace nutrients warrants a high priority for studies of biogeochemical cycles in aquatic systems.

- The interaction of UV-B with other global change factors may act to amplify the impacts of UV-B or other factors and requires further evaluation in order to establish implications for policy in relation to other areas in addition to ozone depletion.

- The prediction of impacts at an ecosystem scale and on biodiversity will require an improvement in knowledge of the effects of UV-B on community structure. In order to integrate information on processes and species it will be necessary to develop methods of modelling the results from experimental studies in order to provide an accurate prediction of ecosystem vulnerability and future long-term impacts.

Human Health

- Although it is currently possible to predict changes in skin cancer incidence in relation to changes in the ozone layer there is much less confidence about prediction of other health effects. Priority should be given to research on other areas of UV-B impacts on human health such as immunological and ocular effects.

- It is recommended that broader impacts of UV-B on human health are studied by means of a comparative epidemiological study of immunological and ocular effects in the UK and a country such as Australia where UV-B exposure is different but population genetics and socioeconomic factors are not too dissimilar. This should be supported by basic studies on molecular, cellular and systemic effects in humans.

Socio-economic Effects

- Given the uncertainties concerning ozone depletion into the next century it would be prudent to support the development and analysis of health education programmes and to improve the accuracy of estimating the social and economic costs of impacts and the strategies for protection of the ozone layer.

Animal Health

- An initial scoping study of UV-B impacts on animal health is needed and it would be desirable to undertake a comparative epidemiological study similar to that recommended for humans.

NATIONAL STRATEGY

- These research recommendations fall within the framework of the UK Global Environmental Research (GER) strategy and provide an input for consideration by research councils, government departments and funding agencies when formulating their own research strategies. The priorities for future research are also consistent with those of the EC Environment and Climate Programme.

- The research themes are a mixture of basic, strategic and applied objectives. Development of a national strategy will require coordination of these priorities across a range of funding agencies (European Commission, government departments and research councils).

1. INTRODUCTION

The First Report of the UV-B Measurement and Impacts Review Group (UMIRG) "The Potential Effects of Ozone Depletion in the United Kingdom" and the Sixth Report of the Stratospheric Ozone Review Group (SORG) "Stratospheric Ozone 1996" were published in November 1996. These Reports reviewed current knowledge to provide a base on which to plan appropriate actions by Government and others, should present measures to control damage to the ozone layer prove less than effective. Following the publication of these Reports a 2-day Workshop was held in Peterborough, UK on 28-29 January 1997 to identify future requirements for UV-B research in the UK and to formulate recommendations for a national strategy for research. Research and monitoring programmes on ozone depletion science were not considered within the scope of the Workshop. Thirty-six representatives of government departments, research bodies and scientists (Table 1) considered summaries of the UMIRG report and other international assessments, formulated recommendations and assigned priorities to future research requirements of the UK. This short report is a synthesis of the discussions and recommendations arising from the Workshop.

2. POLICY REQUIREMENTS FOR RESEARCH ON UV-B

The policy requirements for UV-B research were presented to the Workshop by Mr David Clare of the Department of the Environment, Transport and the Regions as follows:

The world would not be concerned about ozone depletion if it had no material effect on life - it would just be an interesting phenomenon. The motivation and driving force behind all the controls on ozone depleting substances must come from our knowledge of the potential effects they can cause.

In the early debate leading to the Montreal Protocol, the process was driven by a largely unproven science - but nevertheless it was science led. The science addressed how ozone depleting chemicals cause ozone loss, what that means for increased UV-B, and finally what effect that increased UV-B will have. During the 1990s, science has shown that we were right to take action; that ozone depleting chemicals are having a noticeable effect. Since then, the extent to which controls under the Montreal Protocol have been tightened, has depended on technology - the rate at which non-ozone depleting technologies can be developed. That may continue to determine progress over the next few years, but it does not mean that we should abandon further work on the science. We need to be clear about the impact of the anticipated increase in UV-B over the next 50 years, and we need to understand what the effect would be if we subsequently discovered that ozone depletion (and enhanced UV-B) was going to be higher than we had anticipated. Hopefully, we will find that the effects are acceptable (that is the desirable outcome) - but if we do find detrimental impacts, then we will be in a position to respond, either through the Protocol, or by changing behaviour or other remedial actions.

TABLE 1

The following individuals attended the Workshop and provided recommendations from three Working Groups.

Working Group 1. UV-B monitoring, impacts on air quality and materials

Dr Ann Webb (co-chair)	University of Manchester Institute of Science & Technology
Dr Ian Simpson (co-chair)	UK Global Environmental Research Office
Dr John Austin	Meteorological Office
Mr David Clare	Department of the Environment, Transport and the Regions
Dr Duncan Gardiner	Building Research Establishment
Dr Susan Halliwell	Building Research Establishment
Dr Rod Jones	University of Cambridge
Dr David Lee	AEA Technology
Mr David Warrilow	Department of the Environment, Transport and the Regions

Working Group 2. Impacts on Terrestrial and Aquatic Ecosystems

Professor Mike Roberts (co-chair)	Institute of Terrestrial Ecology
Professor Terry Callaghan (co-chair)	University of Sheffield
Dr Stephen Baynes	Centre for Environment, Fisheries and Aquaculture Science
Dr Penny Bramwell	Department of the Environment, Transport and the Regions
Dr Mark Broadmeadow	Forestry Commission
Dr Peter Costigan	Ministry of Agriculture, Fisheries and Food
Dr Clive Cummins	Institute of Terrestrial Ecology
Dr Andrew Farmer	English Nature
Dr Geoff Holmes	University of Cambridge
Mr David Lowe	Plymouth Marine Laboratory
Dr Peter Lumsden	University of Central Lancashire
Mr Iain Massie	Biotechnology and Biological Sciences Research Council
Dr Andy McLeod	Institute of Terrestrial Ecology
Dr Nigel Paul	University of Lancaster
Prof John Raven, FRS	University of Dundee
Dr Diana Wilkins	Ministry of Agriculture, Fisheries and Food
Dr David Wynn-Williams	British Antarctic Survey

Working Group 3. Impacts on Human and Animal Health, Molecular Effects and Socioeconomic Impacts

Dr Jan van der Leun (co-chair)	University Hospital Utrecht, The Netherlands
Mr George Hooker (co-chair)	Department of Health
Dr Colin Arlett	University of Sussex
Dr Rob Bennett	Medical Research Council
Dr Graham Bentham	University of East Anglia
Prof Brian Diffey	Dryburn Hospital
Dr Colin Driscoll	National Radiological Protection Board
Dr J Eric Hillerton	Institute for Animal Health
Mr Alister Scott	University of Sussex

Observer

Dr Keith Harrap	Science Connections Ltd

Written submissions were received from the Wildlife and Countryside Directorate, Department of the Environment, Transport and the Regions and the European Commission.

3. RATIONALE FOR RESEARCH ON THE EFFECTS OF OZONE DEPLETION IN THE UK

It is noted that:

• Policy is in place to phase out ozone depleting substances under the Montreal Protocol but even of it is implemented fully, atmospheric levels of ozone depleting substances will not return to pre-Antarctic ozone hole levels until about the middle of the next century.

• Uncertainties in our ability to predict stratospheric change and the possibility of surprises indicates a risk that ozone depletion could be greater than anticipated. There is already evidence of ozone loss in the Antarctic summer. Currently ozone loss is still increasing more generally. Stratospheric cooling due to ozone loss and increases in greenhouse gases may also enhance ozone depletion.

• Further threats to the ozone layer could come from technological developments with strong economic imperatives, such as the deployment of advanced super-sonic aircraft.

• The Montreal Protocol needs to be implemented fully for several decades. The need for further research is widely recognised in order to continue to address policy questions and to develop response strategies.

• The United Nations Environment Panel (UNEP) assessment on effects of ozone depletion (UNEP, 1994) concludes that research funding is inadequate, globally, and that more should be done. The Scientific Committee on Problems of the Environment Report (SCOPE, 1992) notes that long term research is needed and the World Meteorological Office (WMO)/UNEP Ozone Research Programme Manager's Report of March 1996 (WMO/UNEP, 1996) recommends a more coordinated approach to UV-B measurements and substantial enhancement of effects research. The recommendations of the WMO/UNEP (1996) report were fully endorsed by the Parties to the Vienna Convention in November 1996.

• The Third Report of the British Government Panel on Sustainable Development (DOE, 1997) states "The Panel believes that continued monitoring of the impact of levels of UV radiation is therefore essential to assess the adequacy of measures under the Montreal Protocol."

• The Inter-Agency Committee on Global Environmental Change (IACGEC), UK National Strategy for Global Environmental Research (GER) recognises ozone and UV-B as one of four main integrative themes for GER research.

In summary, further research on the effects of ozone depletion are needed to:

- underpin mitigation effects and provide a rationale for long term protection of the ozone layer.
- cope with existing and projected ozone depletion, to identify important effects and to develop response strategies.

4. CURRENT UNDERSTANDING OF OZONE DEPLETION AND POTENTIAL UV-B IMPACTS

The First Report of the UV-B Measurement and Impacts Review Group (UMIRG) reviewed the current knowledge of the potential effects of stratospheric ozone loss and increased UV-B (UMIRG, 1996). The Report provided recommendations for future research requirements which together with recommendations of other international assessments were considered at the Workshop. The current understanding of potential effects in each subject area was presented by members of the UMIRG and summary statements from UMIRG (1996) are set out below.

4.1 Ozone Depletion and UV-B

• The ozone layer is essential to protect life on Earth from the harmful effects of the Sun's ultraviolet radiation. Global levels of ozone have declined in recent years, and severe ozone depletion is now an annual event in the Antarctic.

• International action has been taken to solve these problems, but the damage to ozone caused by man-made chemicals will not be resolved for many decades. The potential effects of the increased ultraviolet radiation which results from ozone depletion should be examined, in case the remedial measures fail.

• The powerful influence of ozone depletion on ultraviolet radiation fluxes has already been observed in the Antarctic, but ozone is not the only factor determining UV radiative transfer through the atmosphere. Clouds and other atmospheric constituents also affect the amount of ultraviolet radiation reaching the ground.

• The damaging effect of ultraviolet radiation depends on its intensity and its wavelength. Each biological process has its own spectral response, which determines its susceptibility to ozone depletion.

4.2 Measurements and Predictions of ozone and UV

• Ozone depletion has occurred globally outside the tropics. During winter and spring, column ozone has been depleted by about 10% over the UK and northern Europe since the late 1970s, with smaller losses during summer and autumn. Further losses may be expected over the next decade, but precise predictions are uncertain because of a poor understanding of all the atmospheric coupling processes involved.

• There is a continuing need for accurate and continuous measurements of column ozone and solar UV radiation at the earth's surface to establish reliable data records and to identify any changes which may occur.

• Short-term changes in UV have been observed at a number of locations and correlated with low ozone events. However, determining a trend in UV is more difficult than determining a trend in ozone and requires long-term measurements. To date UV measurements in the UK have indicated no significant trend in annually integrated UV. Nonetheless, current UV doses are expected to be higher than they would have been

without ozone depletion.

• UV forecasts for clear skies have been produced for the UK public since the summer of 1994, to provide warnings of sunburn risk.

4.3 Molecular Effects of UV

• Ultraviolet radiation interacts with specific molecules within the cell to produce photodamage.

• Photodamage yield and nature are dependent upon wavelength.

• Photodamage may be modified by molecular repair processes within cells.

• Photodamage generates lethal and mutagenic events leading to cancer.

4.4 Impacts on Aquatic Ecosystems

• There is no doubt that exposure to UVB radiation is detrimental to the biota of the aquatic environment.

• UVB has its greatest impact either at or immediately below the surface of the water where most primary productivity occurs and the eggs and early life stages of many commercially important species of animals reside for some period of their lives. Tidal and intertidal zones of marine and brackish environments, shallow streams and some fish farms are more vulnerable to impact owing to a limited potential to attenuate UVB radiation.

• Anthropogenic contaminants in the water column can photosensitize the biota resulting in enhanced potency of UVB: furthermore, acid rain can mediate a decrease in (UVB attenuating) dissolved organic carbon and increase penetration of UVB in the water column.

• The construction of reliable models of effects for use in risk assessments is problematic due to:

- the absence of a long term data base,
- a limited understanding of the mechanisms of damage,
- a lack of knowledge regarding interactions of UVB with diverse environmental
- variables limited data for the determination of the transparency of UK waters to UVB.

4.5 Impacts on Terrestrial Ecosystems

• UVB radiation affects many organisms which occur in terrestrial ecosystems. The magnitude of such effects in response to ozone depletion is poorly known except for some crop species.

• Increased UVB radiation can modify plant growth and development, leading in some crops to reduced yield. There is scope for plant breeding to develop crops with increased UVB tolerance, particularly in annual species, but which would have limited practical value

for perennial species and natural vegetation.

• Mechanisms by which increased UVB is likely to affect terrestrial ecosystems are predominantly by altering competition between plant species and by interactions of plants with pests, pathogens and decomposers.

• The cumulative effects on terrestrial ecosystems of small but long-term increases in UVB are essentially unknown but may be significant of the function of native ecosystems and biodiversity.

4.6 Impacts on Human Health

• In principle, a reduction in ozone levels could increase the incidence of harmful effects on health that are known to be caused by the UVB radiation in normal sunlight. The principal deleterious effects of UVB radiation are:

- Skin damage, including sunburn, photoageing and skin cancer
- Eye abnormalities, including snow blindness and cataract
- Changes in the immune system, which may alter the course of cancer or infectious disease.

4.7 Impacts on Animals

• Increased UVB may have direct effects on animal health, although most effects will be influenced by the ecological and social systems in which the animals live. Effects are likely to vary between farmed animals, companion animals and wildlife.

• Potential effects to animal health include an increased incidence of sunburn, skin cancer, degenerative eye conditions and changes to the immune system.

• Many of the more significant effects of increased UVB will be indirect and result from changes to the quality of nutrition and availability of shelter for farmed animals, which in turn affect productivity and management regimes. Adaptation to changing UV levels by farmed animals may be achieved through appropriate management; whilst wildlife may be more vulnerable and have to respond naturally.

• So far, the effect of increased UVB on animals is poorly understood, with the exception of some laboratory animal studies that have been undertaken to assess the potential effects of increased UVB levels on man. It is important to understand the effects of increasing levels of UVB on different animals and their responses under managed and natural environments.

4.8 Impacts on Materials

• Materials made from natural or synthetic polymers are widely used in the construction, transport and agricultural industries. When exposed to sunlight (especially UVB) degradation can occur, this is exacerbated by moisture and high temperatures. At first, only the appearance may be affected but in the longer term loss of physical integrity and

function can occur.

• It is now understood how most common polymers can be stabilised so as to provide acceptable durability to weathering. This technology can probably cope with currently anticipated UVB levels, at least in the relatively mild UK climate.

• The use of standardised natural and laboratory weathering tests helps to ensure acceptable performance in use.

4.9 Impacts on Air Quality

• Increases in UV could lead to increases in ozone production over the cities and some downwind areas. increased exceedance of ozone air quality standards in urban areas is anticipated. Rural air quality is likely to be largely unaffected by UV increases.

• The increase in UV resulting from a 5% column ozone reduction increases hydroxyl (OH) radical concentrations by about 4%. In the free troposphere, well above the cities, ozone is depleted, resulting in a 1 to 2% reduction in column integrated tropospheric ozone. Changes are also expected in the tropospheric distribution of HO_2 and hydrogen peroxide.

• Methane (CH_4) is an important greenhouse gas which has been increasing in the atmosphere due to human activities. The expected increase in OH due to the observed global ozone reduction is expected to have reduced CH_4 concentrations by about 4%. However, taking into account the continued release of CH_4, the observed ozone reduction cannot account for all of the observed decreases in the CH_4 growth rate.

• UV at the ground is reduced by the presence of particulate matter and aerosols in the lower atmosphere. Strategies to control particulate pollution will result in increased UV levels.

4.10 Socio-economic factors and impacts

• Increases in UV-related diseases suggest that population exposure to solar ultraviolet radiation has increased. The dominant influence has probably been changes in behaviour. Changes in levels of ultraviolet radiation in the environment have so far probably placed little part in the increase.

• Factors leading to an increase in exposure of the population to solar UV radiation include the growth in foreign holidays, increased participation in outdoor leisure activities, changes in clothing, the continuing popularity of sunbathing and a sun-tanned appearance.

• There is potential for any human health effects of increases in levels of UV radiation in the environment to be mitigated by changes towards more cautious behaviour. However, there are some important obstacles to such changes.

• Socio-economic implications of possible health impacts include costs of treatment, costs of programmes or prevention, the value of lives that are lost and the effects on the tourism and leisure industry of changes in behaviour resulting from perceptions of increased risks.

• There might also be economic implications arising from the effects of enhanced UV on agriculture, forests, fishing and on materials.

5. CURRENT UK RESEARCH PROGRAMME

The potential impacts of ozone depletion and enhanced levels of UV-B operate through or directly impact physical, chemical and biological systems which have been identified in relation to global environmental research as a conceptual framework of three categories: human, physico-chemical and biological systems (IACGEC, 1996). The research interests of the Research Councils and Government Department/Agencies are listed in Annex 1 (adapted from IACGEC, 1996) and include one or more of these three areas (Figure 1). The current and future research activities of the UK Councils and Departments represented at the Workshop are noted below together with a description of European Commission research. Details of individual research projects are included in Annex 2.

5.1 Biotechnology and Biological Sciences Research Council (BBSRC)

The BBSRC has funded research which has now been completed on the effects of UV-B on plants and the molecular basis of these effects as part of its research programme "Biological Adaptation to Global Environmental Change" (BAGEC) which was started in 1992 under the auspices of its predecessor the Agriculture and Food Research Council (AFRC). As part of a Joint Initiative on UV-B effects with the NERC TIGER Programme (see below) BBSRC funded four projects on molecular aspects of DNA damage and the interaction of UV-B and water stress. Some aspects of the BAGEC Programme have been taken forward into a new research initiative "Resource Allocation and Stress in Plants" (RASP) which is commencing in 1997. Two projects on the mechanisms of UV-B effects will form part of the RASP initiative. Details of individual projects are included in Annex 2.

5.2 Natural Environment Research Council (NERC)

The areas of research on stratospheric ozone and UV-B for which NERC has a responsibility encompass both physico-chemical and biological systems and form components of thematic research themes, non-thematic funding (research grants, studentships and fellowships) and the core strategic programmes of its Centres and Surveys.

NERC funds a number of projects with relevance to ozone measurement and prediction including the UK Universities Global Atmosphere Modelling Programme (UGAMP) and the Global Ozone Monitoring Experiment (GOME) on the European Space Agency ERS-2 satellite.

An important component of NERC research on ecosystem impacts of UV-B was undertaken as part of the "Terrestrial Initiative in Global Environmental Research" (TIGER) thematic programme. As part of a Joint Initiative on UV-B effects with the BBSRC BAGEC programme (see above) NERC funded three projects on ecosystem impacts with a fourth project forming part of the TIGER Special Topic awards (detailed in Annex 2).

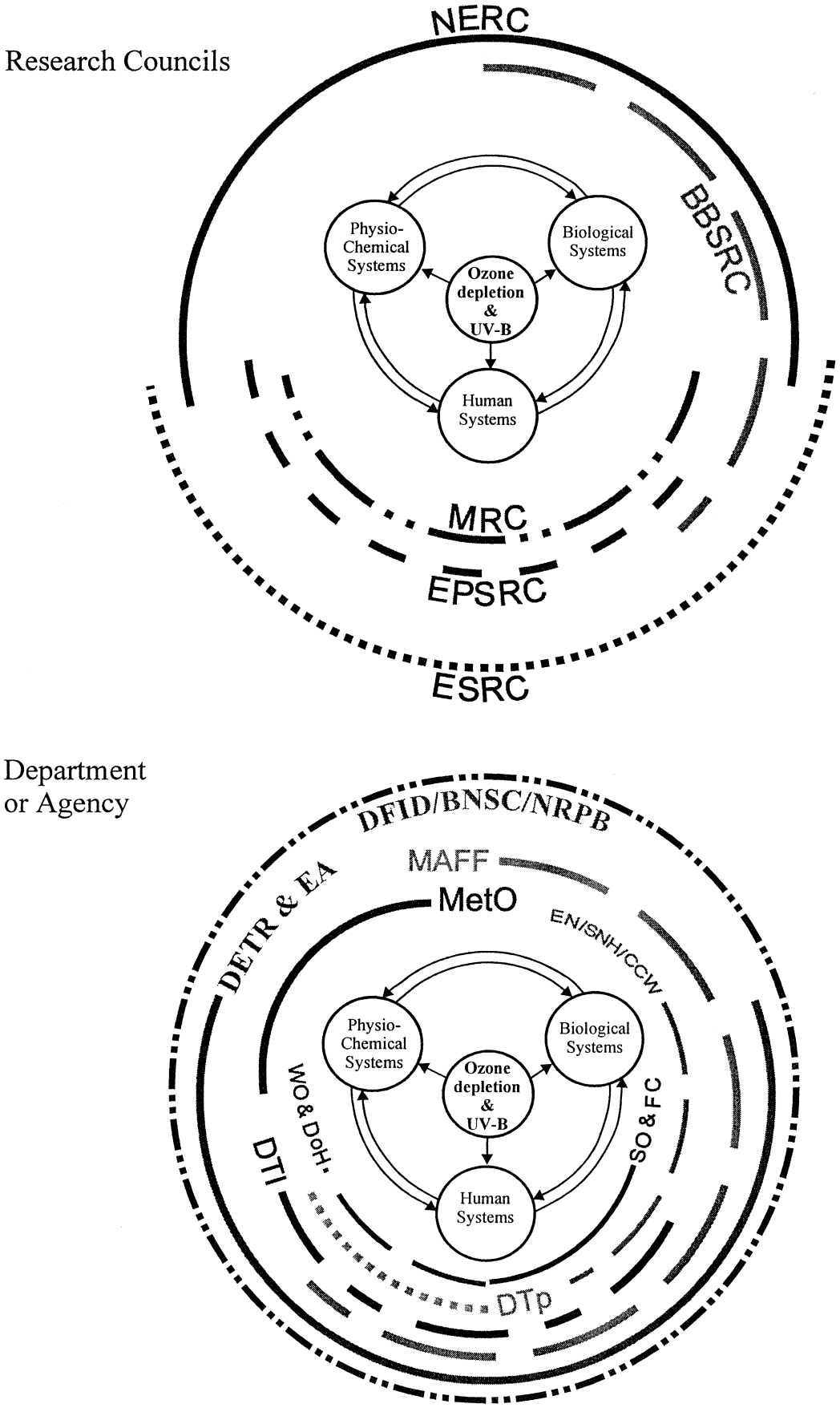

Fig. 1 Research council, government departments, and other funding agency interests in UV-B and ozone depletion. See Annex 3 for acronyms. (Adapted from IACGEC, 1996)

Relevant research of the British Antarctic Survey deals with projects which seek to improve the measurement and modelling of UV-B radiation and to assess the impact of UV-B on Antarctic ecosystems. Details of current and planned projects are included in Annex 2.

The NERC non-thematic programme has funded stratospheric ozone and UV-B research through a research fellowship, one university research grant, five research studentships and one ROPA award (detailed in Annex 2).

5.3 Department of Health (DoH)

The DoH has established a research programme to address the impact of solar UV on skin cancer in humans in response to the Government White Paper "Health of the Nation" which identified skin cancer as a target for health improvement. The key areas of DoH research interest are:

- an assessment of individual risk of developing skin cancer;
- the impact of age and solar exposure;
- the impact of patterns of exposure;
- measurement of exposure;
- cellular aspects of skin damage and repair mechanisms;
- impact of alterations in behaviour;
- the effectiveness of sunscreens;
- the registration of skin cancer patients.

The DoH research programme, which also addresses issues of sunbed exposure, weather forecasts, advertising and long-term increased UV exposure has established 14 projects of up to 3½ years duration at a total cost of £1.7M with contributions to this cost from the Health & Safety Executive (HSE).

5.4 National Radiological Protection Board (NRPB)

NRPB has a continuing programme of solar radiation measurement and has completed over 9 years of measurements at sites across the UK. The NRPB broadband solar radiation measurement systems provide simultaneous and continuous measurements of erythemally effective UV radiation, UVA and photopically weighted visible radiation at six sites spaced at approximately 2^0 latitude. The network comprises two rural sites at Camborne ($\approx 50^0$N) and Chilton ($\approx 52^0$N), two urban sites at Leeds ($\approx 54^0$N) and Glasgow ($\approx 56^0$N) and two coastal sites at Kinloss ($\approx 58^0$N) and Lerwick ($\approx 60^0$N). At two of these sites (Chilton and Glasgow), solar spectral measurements covering the wavelength range 290 to 400 nm are made during daylight every 15 minutes throughout the year. In addition, NRPB provides measurement systems for the Irish Meteorological Service at two of their coastal sites, Mace Head, County Galway ($\approx 54^0$N) and Malin Head, County Donegal ($\approx 55^0$N). Short-term increases in erythemally weighted UV radiation have been recorded at some of these sites at times of recorded low total column ozone, although no significant trends in the annual solar UV radiation levels have been observed over the measurement period. Generally, there is a decrease of about 100 MED (mean erythemal dose) in the annual erythemally weighted UV radiation dose for each degree of latitude increase across the UK, although this depends on localised climatic and atmospheric conditions.

Biological studies at NRPB of the effects of UV radiation are directed towards developing an understanding of the underlying mechanisms involved in the aetiology of UV radiation-induced skin cancer. Emphasis is placed on comparing the relative effectiveness of UVB with UVA, a major component of solar UV radiation and the output of UV solaria. Two studies are currently in progress, one study is investigating the cellular signalling responses elicited in cells cultured from human skin and other cells following exposure to UV radiation, whilst the other is examining the potential for the skin pigment melanin to act as a modifier of UV radiation-induced damage in cultured human melanoma cells. New work to be undertaken will focus on early cytogenetic changes involved in the development of malignant melanoma in humans. Studies will seek to characterise stable cytogenetic and molecular changes in cells cultured from clinical samples of early melanotic skin lesions. In addition, work on UV radiation-induced cytogenetic responses in cultured human melanocytes and in cells cultured from human melanotic lesions will be carried out.

The NRPB Advisory Group on Non-ionising Radiation, an independent panel of leading UK epidemiologists and experimental scientists chaired by Sir Richard Doll with the remit "to review work on the biological effects of non-ionising radiation relevant to human health and advise on research priorities", published a comprehensive review of the health effects of UV radiation (NRPB, 1995).

5.5 Ministry of Agriculture, Fisheries and Food (MAFF)

The MAFF has undertaken research since 1989 on climate change and agriculture in order to provide information on impacts and adaptive strategies as part of a science base for UK agriculture policy. The main areas of research interest involving ozone depletion are on UV-B impacts in agriculture and fisheries. An open contract for investigation of UV-B impacts on crops has been completed and extended further specifically to examine impacts on crop disease. A further project has been completed on the sensitivity of marine fish eggs and larvae to increased UV-B. Effects on crops and fisheries are measurable but not large. Research on climate change effects are continuing but there is no expectation of further funding for UV-B effects research.

5.6 Medical Research Council (MRC)

The MRC research field covers the impact on health of a number of environmental factors including the following which relate to UV-B:

- radiation, whether natural (such as the Sun's rays or natural radioactivity) or man-made (such as pollution from nuclear power stations).

- perturbation of the global environment resulting from man's activities, for example global warming and depletion of the ozone layer.

Many of the environmental influences on health cross national boundaries. The study of environmental factors also requires an interdisciplinary approach which extends beyond the remit of any one organisation and needs to integrate with international programmes in areas

of mutual interest. The MRC strategy is therefore set within the interrelated priorities and research activities of other organisations in the UK, Europe and worldwide and takes account of the needs of government for knowledge to inform legislation and of industry in designing manufacturing processes.

The MRC's approach is:

- to determine the health impact of particular environmental hazards
- establish the biological mechanisms involved
- develop novel scientific approaches to study these problems and new methods to improve quality of life

The MRC funds research on the effects of the physical environment and this is complemented by work on the influences of psychosocial, cultural and economic factors which contribute to variations in health. Relevant research activities are currently funded through specialist units, responsive mode research grants and additional projects. The specialist research units include:

- MRC Cell Mutation Unit, Sussex
- MRC Radiation and Genome Stability Unit, Harwell
- MRC Toxicology Unit, Leicester
- Interdisciplinary Research Centre (IRC) on mechanisms of human toxicity, Leicester

There is a low number of current research and small research grants concerned with UV-B and ozone depletion and new LINK projects which will cover the areas of genetic and environmental impacts on health and psychosocial, cultural and economic factors. These are listed in Annex 2. The total MRC expenditure on these projects in 1995/96 was approximately £400,000.

5.7 Department of the Environment, Transport and the Regions (DETR)

The DETR initiated research on the impacts of ozone depletion in 1989 with a research programme covering: the science of ozone depletion

- ozone monitoring
- monitoring of the gases that cause ozone depletion
- contribution to the European research effort
- modelling of atmospheric processes

and also the impacts of ozone depletion

- UV-B monitoring at Reading, UK
- impacts of UV-B on terrestrial ecosystems including crop plants, microbes, natural vegetation and UV-B climatology
- support activities at the European and international level including spectroradiometric comparisons and contributions to the UNEP assessment

The DETR established the UV-B Measurement and Impacts Review Group (UMIRG) in 1995 which has published its first report and has supported this Workshop as an opportunity to consider the recommendations of UMIRG and other assessments.

5.8 European Commission (EC)

Past and current research efforts of the European Commission (EC) focus on stratospheric ozone depletion, measurement of the UV-B flux at the Earth's surface, UV-B biological dosimetry and the potential impacts of enhanced UV-B flux on health and ecosystems. The research policy of the EC on the fluxes and effects of UV-B radiation are described by Nolan & Amanatidis (1995). Research on ozone depletion and UV-B is implemented at the European Union (EU) level in the ENVIRONMENT research programme of the EC. These activities take the form of field campaigns, concerted actions and shared-cost contract research to achieve the overall objective of providing a firm scientific basis for future EU policy actions. The EC-funded projects which are currently in progress as part of the Environment & Climate Programme are listed in Annex 2.

6. IDENTIFICATION OF PRIORITY RESEARCH AREAS - WORKING GROUP REPORTS

The three Working Groups at the Workshop (Table 1) considered the current knowledge and understanding of the risks of ozone depletion and increased UV-B and established the following priority areas for further research and development in order to underpin mitigation efforts, to provide a rationale for long-term protection of the ozone layer and to identify important impacts that may require further response strategies.

6.1 UV-B Monitoring

6.1.1 **Communication and Co-ordination**. It is considered essential to establish constructive methods of communication between researchers and the beneficiaries of their work including contributions to public awareness. The complex nature of science and the inter-dependence of funding agencies interests has been noted as presenting particular requirements for coordination and collaboration in the context of GER generally (IACGEC, 1996). This applies particularly to the science and funding of UV-B research. An electronic information service would assist researcher -researcher-policy-maker communication. It is essential to coordinate UV-B research with other national activities in related areas (climate change, photochemical oxidants, stratospheric ozone) as well as maintaining links with and participating in international programmes.

6.1.2 **Monitoring of UV-B**. The current UK network of monitoring of UV-B is just adequate to provide information at a national scale. It is essential that the current level of monitoring is maintained and that international links to wider measurement programmes are maintained.

6.1.3 **National and international comparisons of instrumentation**. It is essential to compare monitoring instruments and calibration standards between UK sites and with international networks. Monitoring is of little value without such assurances of accuracy. National representatives in international networks must disseminate knowledge to UK researchers.

6.1.4 **Improve design of instrumentation and calibration facilities.** It is desirable to improve measurement techniques but this requires advances in instruments and calibration methods. This may provide opportunities for commercial organizations. A simple method and protocol is needed for accurate calibration of UV-B measuring instrumentation. It was noted that the National Physical Laboratory are to hold a Workshop on UV measurement.

6.1.5 **Site specific monitoring.** It is essential to undertake some site specific monitoring for detection of impacts. This may be linked to existing sites monitored for environmental change such as the ECN (Environmental Change Network) and so enhance the value of both UV-B measurements and biological observations. It is noted that there is a possible link to assessment of impacts on farm animals.

6.1.6 **Improvement of spatial modelling of UV-B**. It is highly desirable to further develop the national capability to model UV-B levels as a means of interpolation between monitoring sites. Although modelling of UV-B under clear skies is reasonable this capability should be developed to allow for cloud and other climate factors. There are clear links with databases on satellite ozone measurement, cloud top albedo elevation and topography. It is noted that the ability to predict ozone depletion and UV-B levels with accuracy over the UK are critical for prediction of impacts on material, ecosystems, human and animal health and socioeconomic impacts.

6.2 Impacts on Materials

6.2.1 **Measurement and modelling of impacts on materials**. It is highly desirable to investigate the impacts of measured levels of UV-B on materials in relation to their spatial distribution and exposure as few form a horizontal surface. This should involve modelling of UV-B exposure and has a link to recommendation 6.1.4 above.

6.2.2 **Determine extreme and threshold events for materials damage**. The threshold for damage to materials under extreme UV conditions should be established in relation to other environmental factors, such as temperature and dry deposition of atmospheric pollutants.

6.2.3 **Establish standardized weathering tests for materials**. It is desirable to establish standard UV weathering tests for materials both within the UK and globally.

6.3 Impacts on Air Quality

6.3.1 **Evaluate secondary impacts of ozone depletion via changes in tropospheric air quality**. An increase in UV-B levels will lead to some increases in ground level ozone concentrations and this may itself have impacts which it is desirable to quantify.

6.4 Terrestrial and Aquatic Ecosystems

The Working Group dealing with ecosystems identified that similar future research requirements may have different priorities within the range of habitats and ecosystems. The subjects and priorities were therefore addressed within four sub-groups which each identified their own research requirements and priorities. The sub-groups were:

- Policy requirements
- Marine and freshwater systems
- Forestry and crops
- Ecology and microbiology

The policy requirements below were identified and considered by the three other sub-groups in discussion of their own research priorities.

Policy Requirements

The objectives of future research of UV-B effects on ecosystems are to obtain reassurance that controls put in place under the Montreal protocol will protect ecosystems. There are currently considerable uncertainties about UV-B impacts in both terrestrial and aquatic ecosystems identified in the UMIRG report (UMIRG, 1996). The key information required to determine future policy must address the following:

• *Risk assessment.* The diversity of ecosystems and species sensitivity requires quantification for the UK in order to identify the degree of risk to those ecosystems that may be particularly vulnerable or will be exposed to increased UV-B in order to allow prediction of impacts at a national level.

• *Recognisable Impacts.* Development of policy requires that we understand whether ecosystem impacts are trivial or significant (particularly long-term cumulative effects), whether they are reversible or irreversible and whether they can be managed by strategies to achieve mitigation or adaptation, or whether they are unmanageable.

• *European and International Coordination.* The risks to UK ecosystems must be understood in relation to those of neighbouring countries and global impacts.

• *Interactions.* Certain ecosystems may already be under pressure from other factors (such as pollution) which may have policies in place for their control. It is important to know whether UV-B will interact with other factors to increase risks which may influence policy decisions.

• *Surprises.* Is there a risk of surprise impacts on ecosystems that arise from differences in effects of slow changes in UV-B compared to large step changes in UV-B?

• *Adaptation.* To what extent can ecosystems adapt to changes in UV-B and can this be accelerated?

These policy requirements were considered by the other sub-groups and the entire Working Group to determine the following priority areas for ecosystem research.

6.4.1 **Experimental Technology**. Future effects research should be undertaken using appropriate action spectra and the best available methodologies for long-term studies with appropriate UV-B doses and under realistic environmental conditions. Consequently:

6.4.1.1. Studies of UV-B impacts on ecosystems are critically dependent upon some aspects of the methods and equipment chosen. There is significant uncertainty about the accuracy of action spectra, which define wavelength dependency of biological response, and the importance of lamp UV-A emissions in experiments. UV-B dose response information is required but this is itself dependent upon knowledge of appropriate action spectra. It is essential to complete a **desk study evaluation of** the sensitivity of effects data and predicted impacts to the nature of **action spectra and dose-responses**.

6.4.1.2. It is highly desirable to **determine action spectra** for key ecosystem components and processes **under field conditions** and over appropriate experimental periods.

6.4.2 **Assessment of species sensitivity and variability**. It is not currently possible to identify key ecosystems and species that are particularly vulnerable to increased UV-B although some knowledge of variation between and within agricultural crops is broadly known. It is essential to determine the variability of sensitivity for a wide range of plant and animal species representative of different ecosystems, habitats and critical ecosystem functions. This will identify key targets for protection which should be monitored most closely for future impacts. Assessments must evaluate the extent of intra-specific variation and the existence of ecotypes adapted to specific locations and UV-B climate. An underlying principal for assessments is the need for long-term studies in order to detect cumulative effects of small changes in UV-B and the timing of ozone depletion episodes with vulnerable developmental stages. Perennial species and forestry trees in particular are a high priority for study.

6.4.3 **Physiological Basis of Sensitivity**. The mechanisms of response to UV-B are unknown for many organisms apart from some crop species. Although establishment of species vulnerability is a higher priority it is also highly desirable to understand the physiological or behavioural basis for tolerance or sensitivity as this may provide information on adaptive strategies.

6.4.4 **Influence of genetic changes on fitness.** UV-B has a direct and damaging effect on DNA and may consequently have an impact on mortality and fecundity as genetic damage is expressed in subsequent generations. Short-lived organisms are likely to be most rapidly affected and this mechanism for impacts is less likely to be of importance for perennial species such as forest trees. Whilst of lower priority than the identification of species sensitivity to UV-B it is very important to evaluate the importance of this fundamental mechanism for detrimental effects on ecosystems.

6.4.5 **Impacts on biogeochemical cycles.** Biogeochemical cycles are responsible for the availability of nutrients in ecosystems and also the fluxes of certain greenhouse and chemically important trace gases to the atmosphere. Biogeochemical cycles are complex processes of biological, chemical and physical systems in time and space. In order to understand the impacts of UV-B on these processes it will be necessary to examine effects in the short-term but to evaluate their long-term impact on ecosystem productivity. Such studies are highly desirable for terrestrial ecosystems. However, the reported effects of UV-B in marine ecosystems, including effects on the degradation of dissolved organic matter, sulphur cycles and the bioavailability of trace nutrients warrants a high priority for such studies in aquatic systems.

6.4.6 **Interactions with other global change factors.**

Many other global factors are changing and it is consequently important to evaluate the significance of interactions between increased UV-B and other parameters such as temperature, increasing carbon dioxide concentration and ground-level ozone concentration. This is required in order to determine whether UV-B impacts are amplified by other factors or whether detrimental impacts of other changes are amplified by increases in UV-B. In the marine environment it is particularly necessary to consider the interaction of UV-B with toxic contaminants as a mechanism for increased toxicity. Knowledge of how increased UV-B interacts with climatic change factors, particularly temperature, and with elevated carbon dioxide concentration are a particular priority for agriculture and forestry.

6.4.7 **Impacts on community structure and biodiversity**

It is highly desirable to improve knowledge of UV-B effects on community structure in ecosystems as impacts on sensitive species and processes will have consequent effects on species of other trophic levels and this may modify species composition, biodiversity and community structure and function. Whilst this is a lower priority than the determination of species sensitivity an understanding of impacts at the community level is essential for prediction of impacts at the ecosystem scale.

6.4.8 **Modelling for prediction of vulnerability**

In order to integrate the research knowledge on other aspects of ecosystem impacts (detailed above) it will be highly desirable to develop methods of modelling the results from experimental studies and monitoring in order to permit an accurate prediction of ecosystem vulnerability and future long-term impacts.

6.5 Impacts on Human Health

Although it is currently possible to predict changes in skin cancer incidence with changes to the ozone layer using existing information and assuming that clothing usage and behaviour outdoors remains unchanged, there is much less confidence about the ability to predict the consequences of ozone depletion on other health effects. Priority should therefore be given to researching other areas of UV-B health impacts such as immunological and ocular effects.

6.5.1 **Comparative epidemiology studies of immunological and ocular effects in humans**. In the context of the UK population, it would be beneficial to exploit the incidence of these diseases in Australia and New Zealand, which have natural solar environments with UV levels comparable to severe ozone depletion over the UK. Comparative epidemiological studies with the UK would be meaningful because of the similarities in both population genetics and socio-economic environments.

The studies should investigate the following areas:

- incidence of infectious diseases common to the three countries
- possible reduced efficacy of vaccines
- possible reduced efficacy of antibiotics
- photo-degradation of systemic medications leading to reduced clinical efficacy
- incidence of non-Hodgkin's Lymphoma, where immune suppression is a known risk factor
- the putative protective effects of sun exposure on breast cancer and colon cancer.

For cataracts, there is a need to disentangle any effects of UV exposure from dietary and other influences. There is potential to build on information collected as part of EPIC (the on-going European cancer cohort study).

6.5.2 **Basic studies on molecular, cellular and systemic effects in humans**. It will become necessary to substantiate the above epidemiological findings by basic studies on molecular and cellular and systemic mechanisms.

6.5.3 **Development and analysis of health education programmes**. Given the uncertainties concerning ozone depletion into the next century, it would be prudent to support the further development and analysis of the existing health education programmes aimed at encouraging people to limit their sun exposure. Research could build on current ESRC-sponsored work on the perception, communication and management of risk.

6.6 Socio-economic Impacts

6.6.1 **Improved estimation of social and economic costs**. As a result of reduced uncertainties in the science of ozone changes and impacts, it may become possible to make more accurate estimates of the social and economic costs of ozone depletion and the benefits of strategies to further protect the ozone layer.

6.7 Impacts on Animal Health

6.7.1 **Scoping study of animal impacts**. An initial scoping study of animal impacts is required to determine: international recognition of potential impacts on all types of animals; programmes in place to study these impacts; and remedial approaches being implemented. This will allow an evaluation of any necessary complementary work and avoid the duplication of effort.

6.7.2 **Comparative epidemiology studies of immunological and ocular effects in animals**. It would be possible and desirable to undertake a similar study on selected farm animals to that proposed for human health, as proposed above, with an emphasis on infectious disease and ocular disease. As with the human study, a comparative study of the Australian/New Zealand and UK situations is possible because of the similarities in genetics and farming practice.

7. BROADER RESEARCH REQUIREMENT

Research on ozone depletion and UV-B measurement and impacts form a component of the wider definition of global environmental research (GER) for which a UK National Strategy has been developed by the Inter-Agency Committee on Global Environmental Change (IACGEC) under the direction of the Office of Science and Technology (OST) (IACGEC, 1996). The UK GER strategy identifies the relationship between GER issues, economic sectors and Technology Foresight Priorities (Annex 2 of IACGEC, 1996). The recommendations for research on the impacts of ozone depletion are highly important to UK economic interests and have links to international priority concerns and many associated and legal developments. The conceptual framework for the UK GER strategy identifies three main components or perspectives: (Figure 1)

- *Underpinning Research* that concerns single-discipline studies within the categories of human, physico-chemical and biological systems.

- *Interactive Research* that involves links between two or more components of the human, physico-chemical and biological systems.

- *Systemic Research* which spans all three components of the human, physico-chemical and biological systems and addresses overarching questions with a global dimension.

Stratospheric ozone and UV-B are identified components of all three research categories with ozone and UV-B noted as one of the four major areas for systemic research.

The recommendations of this workshop defined above (Section 6) fall within the GER categories of research directions and priorities (Table 2). The majority of recommendations identify key uncertainties and new scientific issues in the underpinning research category. However, many of the recommendations provide an evolving input to interactive and systemic research categories which are indicated in Table 2.

Recognition of the scientific importance of many of these recommendations is apparent from the recent and current work supported by one or more of the UK funding agencies (Section 5 and Annexes). The recommendations (Tables 2 and 3) provide a focus for the consideration of areas which have not been previously funded adequately or emerging areas of scientific importance.

The large number of national funding bodies supporting work relevant to GER is illustrated in Figure 1 and activities related to impacts of ozone depletion are listed in Annex 1

Table 2	Research Recommendations in the framework of the UK GER Strategy		Underpinning research	Interactive research	Systemic research
Physico-chemical systems	**6.1**	**UV-B Monitoring**			
	6.1.1	Communication and coordination	- - - - - - - - - - - -	==========	- - - - - - - - - - - -
	6.1.2	Monitoring UV-B	==========	- -	
	6.1.3	National and international comparisons	==========		
	6.1.4	Improvement of UV-B modelling	==========	- -	
	6.1.5	Improve design of instrumentation and calibration	==========		
	6.1.6	Site specific monitoring	- - - - - - - - - - - -	==========	
	6.2	**Impacts on Materials**			
	6.2.1	Measurement and modelling of impacts on materials	==========	- -	
	6.2.2	Determine extreme and threshold events for material damage	==========		
	6.2.3	Establish standardized weathering tests for materials	==========		
	6.3	**Impacts on Air Quality**			
	6.3.1	Evaluate impacts via changes in tropospheric air quality	==========	- -	
Biological systems	**6.4**	**Impacts on Terrestrial and Aquatic Ecosystems**			
	6.4.1	Experimental Technology	==========		
	6.4.2	Assessment of species sensitivity and variability	==========		
	6.4.3	Physiological Basis of Sensitivity	==========		
	6.4.4	Influence of genetic changes on fitness	==========	- - - - - - - - - - - -	
	6.4.5	Impacts on biogeochemical cycles		- - - - - - - - - - - - - -	==========
	6.4.6	Interactions with other global change factors		==========	- - - - - - - - - - - -
	6.4.7	Impacts on community structure and biodiversity	==========	- -	
	6.4.8	Modelling for prediction of vulnerability		==========	- - - - - - - - - - - -
	6.7	**Impacts on Animal Health**			
	6.7.1	Scoping study of animal impacts	==========		
	6.7.2	Comparative epidemiology of immunological and ocular effects		==========	
Human systems	**6.5**	**Impacts on Human Health**			
	6.5.1	Comparative epidemiology of immunological and ocular effects		==========	
	6.5.2	Basic studies on molecular cellular and systemic effects	==========		
	6.6	**Socioeconomic Impacts**			
	6.6.1	Development and analysis of health education programmes	==========		
	6.6.2	Improved estimation of social and economic costs		==========	- - - - - - - - - - - -

(adapted from Table 3 of IACGEC, 1996). The existence of recent and current research projects on UV-B impacts greatly enhances the ability of the UK to participate in, and benefit from, international research activities and policy initiatives. The UK GER strategy identifies relationships between UK research and international GER projects and programmes. The European Commission's Research and Development Framework IV Programme (1994-98) has a large number of projects related to impacts of ozone depletion (Annex 2): of the 13 projects listed, nine have at least one UK partner.

The UK GER strategy has noted the need for development of communication and coordination of research activities on aspects of global change in order to achieve the necessary interactive and systemic research dimension required to address policy issues. This Workshop has also identified this as a critical area for assessment of the impacts of ozone depletion. Recommendations of the national GER strategy for research coordination are particularly appropriate for ozone and UV-B research.

8. CONCLUSIONS

This Workshop has considered the conclusions of the First UMIRG Report and other international assessments in relation to the policy requirements for future research on UV-B in the UK. There remain limitations in our ability to predict changes in stratospheric ozone and impacts of increased UV-B on aspects of human health, ecosystems, air quality, materials and socio-economic effects.

Further research on the science of ozone depletion and its impacts are needed in order to .

- underpin mitigation effects and provide a rationale for long term protection of the ozone layer.

- cope with existing and projected ozone depletion, to identify important impacts and to develop response strategies.

The Working Groups considered the policy requirements and identified the scientific issues, consequent research needs and the achievable research opportunities. These have been noted as research recommendations for which priorities have been identified within each subject area. The priorities are summarized in Table 3.

These research recommendations fall within the framework of the UK GER strategy and provide an input for consideration by research councils, government departments and funding agencies when formulating their own research strategies. These priorities are also consistent with those of the EC Environment Programme. The research themes are a mixture of basic, strategic and applied objectives. Development of a national strategy will require coordination of these priorities across a range of funding agencies (EC, government departments and research councils).

Table 3 Priorities of Research Recommendations	Essential	Highly Desirable	Desirable
6.1 UV-B Monitoring			
6.1.1 Communication and coordination	✓		
6.1.2 Monitoring UV-B	✓		
6.1.3 National and international comparisons	✓		
6.1.4 Improve design of instrumentation and calibration			✓
6.1.5 Site specific monitoring	✓		
6.1.6 Improvement of UV-B modelling		✓	
6.2 Impacts on Materials			
6.2.1 Measurement and modelling of impacts on materials		✓	
6.2.2 Determine extreme and threshold events for material damage		✓	
6.2.3 Establish standardized weathering tests for materials			✓
6.3 Impacts on Air Quality			
6.3.1 Evaluate secondary impacts via changes in tropospheric air quality			✓
6.4 Impacts on Terrestrial and Aquatic Ecosystems			
6.4.1 Experimental Technology			
6.4.1.1 Desk study of action spectra and dose responses	✓		
6.4.1.2 Determine action spectra under field conditions		✓	
6.4.2 Assessment of species sensitivity and variability	✓		
6.4.3 Physiological Basis of Sensitivity		✓	
6.4.4 Influence of genetic changes on fitness		✓	
6.4.5 Impacts on biogeochemical cycles			
6.4.5.1 In aquatic ecosystems	✓		
6.4.5.2 In terrestrial ecosystems		✓	
6.4.6 Interactions with other global change factors		✓	
6.4.6.1 In terrestrial ecosystems	✓		
6.4.7 Impacts on community structure and biodiversity		✓	
6.4.8 Modelling for prediction of vulnerability		✓	
6.5 Impacts on Human Health			
6.5.1 Comparative epidemiology study of immunological and ocular effects	✓		
6.5.2 Basic studies on molecular cellular and systemic effects		✓	
6.6 Socio-economic Impacts			
6.6.1 Development and analysis of health education programmes		✓	
6.6.2 Improved estimation of social and economic costs		✓	
6.7 Impacts on Animal Health			
6.7.1 Scoping study of animal impacts	✓		
6.7.2 Comparative epidemiology study of immunological and ocular effects		✓	

9. REFERENCES

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UMIRG (1996) The Potential Effects of Ozone Depletion in the United Kingdom. First Report of the United Kingdom UV-B Measurement and Impacts Review Group. HMSO, London.

UNEP (1994) Environmental effects of Ozone Depletion: 1994 Assessment. United Nations Environment Programme, Nairobi, Kenya, November 1994 (ISBN 92-807-1457-0).

WMO/UNEP Ozone Research Programme Managers Report (March 1996)

Annex 1. Research Council and Government Department/Executive Agency interests in Ozone Depletion and UV-B Research (adapted from IACGEC, 1996)

	Research Councils
Biotechnology & Biological Sciences (**BBSRC**)	Resource allocation and stress in plants. Research strategy towards sustainable agriculture.
Economic & Social Research (**ESRC**)	Human drivers of environmental change (population dynamics; economic activity; individual and corporate perceptions, attitudes and behaviour). Socio-economic impacts of change: environmental risk assessment techniques and uncertainty. Technological change and the management of innovation; the use, diffusion and effectiveness of clean technologies to reduce greenhouse gas emissions and pollution. National and international policy formulation and implementation. Sustainable development including local responses/community initiatives.
Engineering & Physical Sciences (**EPSRC**)	Development of clean technologies to reduce emissions of greenhouse gases and pollution; cleaner and more efficient combustion systems and synthesis; sustainable cities;
Medical (**MRC**)	Human population dynamics as a driver of environmental change; Impacts of climate change, UV-B and tropospheric pollution on human health.
Natural Environment (**NERC**)	Processes within and between the atmosphere, ocean, sea ice, terrestrial systems, (including clouds, fluxes of energy, nutrients and gases). Earth radiation budget studies. Spatial and temporal variability. Observational and modelling studies to improve and quantify understanding of the primary sources, chemical interactions and transport of gases and particulates in the troposphere. Influence of polar regions on global systems and their response to environmental change. Integrated atmospheric, hydrological and biological modelling of impacts on land surfaces. Impacts of climate change, increased UV-B radiation and atmospheric pollution on ecosystems. Factors controlling the origins, maintenance and loss of biological diversity and how changes affect ecosystem processes; factors influencing distribution and abundance of organisms and community assembly

Government Departments and Executive Agencies	
Agriculture, Fisheries & Food (**MAFF**)	Impacts of climate change on agriculture
British National Space Centre (**BNSC**)	Earth Observation satellites: ERS1 & 2; ENVISAT and Polar Platform.
Conservation Bodies (**EN/SNH/ CCW**)	Countryside Council for Wales, English Nature and Scottish Natural Heritage: Protection and sustainable use of Welsh , English and Scottish ecosystems respectively - impacts of climate change, land use change and pollution.
Environment (**DETR**)	Monitoring, prediction, scale and causes of anthropogenic climate change and stratospheric ozone depletion. Impacts of climate change and ozone depletion. Better understanding of sources, especially of particles, of ozone on a European scale, and quantification of improvements to air quality, of the costs of control measures and of exposures of populations to air pollutants. Ensure adequate management of water supplies and protect UK freshwater and marine environment. To assist in conserving biodiversity and natural habitats globally. Policy lead Climate Change Convention, Montreal Protocol and Biodiversity Convention.
International Development (**DFID**)	Environmental sustainability in developing countries; research covering greenhouse gases, climate change, ozone, forestry, water and food.
Environment Agency (**EA**)	Protection and sustainable use of UK water resources - impact of climate change. Modelling pathways of pollutants through the environment and estimating pollutant impacts, including critical loads assessment methods to power station emissions improvement plans.
Forestry (**FC**)	Protection and sustainable exploitation of forestry resources
Health (**DoH**)	Health impacts of climate change, increased UV-B radiation and atmospheric pollution
Meteorological Office (**MetO**)	Development of coupled and unified models for monitoring, measuring and predicting climate change.
Scottish Office (**SO**)	Impacts on Scottish agriculture and fisheries.
Trade & Industry (**DTI**)	Development of cleaner technologies for energy provision and greenhouse gas abatement -specifically initiatives for cleaner coal technologies and the development of renewable energy technologies.
Transport (**DTp**)	Greenhouse gas emissions from the transport sector and climate change consequences of those emissions. Atmospheric pollution and transport sector.
Welsh Office (**WO**)	Impacts of climate change and atmospheric pollution.

ANNEX 2 Current research projects related to UV-B and ozone depletion of the UK Research Councils, Government Department/Agencies and the European Commission

Research projects of the BBSRC

Biological Adaptation to Global Environmental Change (BAGEC) Programme

The interaction of enhanced UV-B and water stress on oilseed rape cultivars with differing UV-B sensitivity.
1993-1996 £200,000 University of Cambridge

The molecular basis of UV-B perception and response in plants.
1993-1996 £119,943 University of Glasgow

Effects of UV-B irradiation on cell cycle gene expression and DNA repair in developing wheat (*Triticum aestivum* L.) leaves.
1993-1996 £164,656 University of Manchester, HRI Wellesbourne, University of St. Andrews

Molecular mechanisms involved in ultraviolet-B induced changes in gene expression for photosynthetic proteins
1993-1996 £139,696 HRI, Wellesbourne

Resource allocation and Stress in Plants (RASP) Programme

The biochemical and genetic basis of UV-protection
1997-2000 £189,216 University of Glasgow

Characterisation of higher plant photolyase genes and analysis of their role in protection from ultra-violet radiation
1997-2000 £191,564 University of Manchester

Research Projects of NERC

NERC TIGER Programme

The response of native vegetation to enhanced UV-B radiation
1993-1996 £111,000 UCPE, Sheffield and University of Lancaster

Effects of increased UV-B on the vegetation of natural ecosystems
1993-1996 £129,000 ITE Monks Wood, University of Cambridge, University of Essex

Effects of elevated UV-B radiation on the chemical composition and decomposition of oak litter
1994-1997 £130,000 ITE Monks Wood and ITE Bangor

NERC Non-thematic Funding

Research Fellowship: Response of Arctic vegetation to environmental stresses (including UV-B) University of Sheffield.

Research Award: Effects of elevated UV-B radiation (280-320 nm) on the litter quality and decomposition of *Rubus chamaemorus* and *Calluna vulgaris*.
1993-1996 £138,000 University of Lancaster and ITE Merlewood

ROPA Award: Instrumentation characterising aerosol radii using sun photometry (ICARUS)
1995-1996 £30,000 RSADU, Monks Wood

Research Studentships

NERC research studentships currently provide £28520 per award over a three-year period.

Responses of Arctic plants to UV-B radiation
University of Sheffield

Effects of UV-B irradiation on plant respiration
University of St. Andrews

CASE Award: Raman spectroscopy of protective pigments in lichen
University of Bradford and BAS

Effects of global warming and UV lights on microbial activity in Antarctic soils
University of Kent

Phenotypic and genotypic responses of aquatic bacteria to elevated UV-B levels
University of Liverpool

NERC British Antarctic Survey Projects

Microalgal colonization processes during field simulated warming with and without UV stress

Modelling UV flux and quality with respect to latitude, season and atmospheric aerosols

Biological production of UV-protective pigments under increased and decreased UV radiation

Effect of UV radiation on photosynthetic systems in cryptogams and grass

Accumulation of Scytonemin in cyanobacterial exopolysaccharide sheaths

Lichen ecophysiology under UV stress

Biological UV dosimetry in Antarctica and Earth orbit

UV-screening effect of lithic habitats and biological pigments in Antarctic endolithic communities under the ozone hole and in Earth orbit

Responses of microalgae and cryptogams to UV-stress in the field and controlled environment cabinets

Biological production of UV-protective pigments under increased and decreased UV radiation

Research Projects of MAFF

Responses of crops to UV-B radiation
1994-1996 £215,000 University of Lancaster

Effects of ultraviolet-B radiation on crop disease
1996-1997 £52,000 University of Lancaster

Effects of UV-B on fish eggs and larvae
1993-1996 Centre for Environment, Fisheries & Aquaculture Science, Conwy

Research Projects of DETR

Ozone Layer - Impacts

Ultraviolet measurements
1989-1996 £284,839 University of Reading

The impact of increased UVB radiation on vegetation
1989-1995 £507,380 University of Lancaster

The impact of increased UVB readiation on terrestrial ecosystems
1996-1997 £119,026 University of Lancaster

Research Projects of the Department of Health (DoH)

Human cellular response to specific UV photoproducts from sunlight and sunbeds
1996-1999 £104,937 MRC Cell Mutation Unit, Brighton

Measurement of spectral output of sunbeds
1996-1997 £32,479 University of Glasgow

Effective registration of skin cancer in Yorkshire
1996-1999 £97,332 University of Leeds

Dietary factors affecting the carcinogenic potential of sunlight
1996-1999 £17,340 University of Cambridge

A study of skin ageing and naevi in relation to natural and artificial UV exposure and sunburn in young women
1996-1999 £235,179 London School of Hygiene and Tropical Medicine

Development of a rapid, non-invasive method for evaluating sunscreen application and performance in vivo
1996-1998 £56,976 University of Newcastle

Clothing protection and sun exposure
1996-1998 £75,521 National Radiological Protection Board

Skin-type dependent risk factors in skin cancer: their modification in tanning and sunscreens
1996-1999 £332,690 St Thomas' Hospital and University of Manchester

Endogenous protection from and sensitisation to UVA damage
1996-2000 £343,241 University of Bath

The role of melanocyte stimulating hormone receptor mutants in melanoma: A case control and population study
1996-1997 £71,715 University of Newcastle

Evaluation of sunburn times by weather forecasters
1996 completion £44,063 Research Works Limited

Effects of pollution control on UV exposure
1996-1997 £19,747 AEA Technology

Magazine coverage of information regarding protection from the sun
1996 completion £41,713 Health Education Authority

Research Projects of the NRPB

The following projects receive core funding:

Biological Studies

Signalling responses in human cells following UVR exposure

Potential of the skin pigment to melanin to modify UVR-induced DNA damage.

UVR-induced cytogenetic changes in human melanocytes and early melanotic lesions

Characterisation of stable cytogenetic and molecular changes in early melanotic lesions

Development of staining techniques for quantitating UVR-induced oxidative damage to DNA in human skin cells (EMR Contract).

Physical Studies

Measurements of solar radiation levels and the interpretation of the impacts of these measurements and their temporal variation on human health.

Research Projects of the MRC

MSH receptor mutations in man. University of Newcastle-upon-Tyne

DNA damage, repair and mutation in relation to gene structure and the mitotic cycle of *Saccharomyces cerevisiae*. University College Wales

MSH, its mechanisms of action and receptor binding in human melanocytes *in vitro*. University of Newcastle-upon-Tyne

The effects of ultra-violet light irradiation and urocanic acid on dendritic cells. University of Edinburgh

Regulation of the G1-S phase transition in fission yeast. University of Edinburgh

Protein-DNA interactions in recombination and DNA repair. University of Nottingham

Research Projects of the European Commission

The following EC-funded projects are currently in progress as part of the Environment & Climate Programme. The location of Coordinators (and UK partners) is noted.

Topic 1.2.2.2 Alterations of processes as a result of UV-B radiation

The detection of UV-B damage and characterisation of its biological consequences in the cellular components of human skin.
1996-1999 1,100,000 ECU MRC Cell Mutation Unit, Brighton

Direct versus indirect ultraviolet light-induced DNA damage in the genesis of human melanoma and non-melanoma skin cancer.
1996-1999 900,000 ECU Human Cancer Genetics Unit, Brunel University

Effects of ultraviolet radiation on marine microalgae and seagrasses (UV/marine macrophytes).
1996-1999 1,000,000 ECU Alfred-Wegener-Institut, Bremerhaven, Germany

ELDONET - Installation of a European light dosimeter network
1996-2000 154,200 ECU Friedrich-Alexander-Universitat, Nurnberg, Germany

Health effects of UV-B exposure with special emphasis on infections in man
1996-1998 1,100,000 ECU Rijksinstituut voor Volksgezondheid en Milieuhygiene, Bilthoven, The Netherlands
(University of Edinburgh)

Effects of UV-B in humans: photoproducts and their transformation to p53 mutations as risk indicators.
1996-1999 375,000 ECU KarolinskaInstitute, Stockholm, Sweden
(Imperial Cancer Research Fund, London)

The effects of UV-B radiation on sensitive European ecosystems
1996-1999 1,099,200 ECU University of Sheffield

Topic 1.2.1.1 Stratospheric chemistry and depletion of the ozone layer

Photochemical activity and solar ultraviolet radiation (PAUR)
1996-1998 355,000 ECU Aristotle University of Thessaloniki, Greece

Experimental study of the altitude dependence of the tropospheric ozone photolysis frequency J(01D) between 0 and 12 km height.
1996-1998 316,000 ECU Forschungszentrum Jülich GmbH, Jülich, Germany
(University of Oxford)

Ultraviolet radiation in the Arctic - past, present and future
1996-1999 600,000 ECU Finnish Meteorological Institute, Helsinki, Finland

Scientific UV data management
1996-1999 900,000 ECU Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung e.V., Garmische-Partenkirchen, Germany
(UMIST)

Topic 2.1.5 Stratosphere

Development of biological dosimetry systems for monitoring the impact of solar UV-B radiation on the biosphere and human health - BIODOS.
1996-1998 300,000 ECU Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V., Koln, Germany
(UMIST)

Standardisation of ultraviolet spectroradiometry in preparation of a European Network (SUSPEN).
1996-1998 265,300 ECU Aristotle University of Thessaloniki, Greece
(British Antarctic Survey, Cambridge; UMIST)

ANNEX 3 - Acronyms and abbreviations

BAGEC	Biological Adaptation to Global Environmental Change
BAS	British Antarctic Survey
BBSRC	Biotechnology and Biological Sciences Research Council
BNSC	British National Space Centre
CCW	Countryside Council for Wales
CFC	Chloroflourocarbon
DETR	Department of the Environment, Transport and the Regions
DFID	Department for International Development
DoH	Department of Health
DTI	Department of Trade and Industry
DTp	Department of Transport
EA	Environment Agency
EC	European Commission
ECN	Environmental Change Network
EN	English Nature
EPSRC	Engineering and Physical Sciences Research Council
ESA	European Space Agency
ESRC	Economic and Social Research Council
FC	Forestry Commission
GER	Global Environmental Research
HRI	Horticultural Research International
HSE	Health and Safety Executive
IACGEC	Inter-Agency Committee on Global Environmental Change
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Programme
IPCC	Intergovernmental Panel on Climate Change
MAFF	Ministry of Agriculture, Fisheries and Food
MED	Mean Erythemal Dose
MetO	Meteorological Office
MRC	Medical Research Council
NERC	Natural Environment Research Council
NRPB	National Radiological Protection Board
OECD	Organisation for Economic Cooperation and Development
OST	Office of Science and Technology
RASP	Resource Allocation and Stress in Plants
ROPA	Realising Our Potential Award
SCOPE	Scientific Committee on Problems of the Environment
SNH	Scottish Natural Heritage
SO	Scottish Office
TIGER	Terrestrial Initiative in Global Environmental Research
UNCED	United Nations Conference on Environment and Development
UV-A	Ultraviolet radiation (of wavelenght 315-400nm)
UV-B	Ultraviolet radiation (of wavelength 280-315nm)
WO	Welsh Office