THE PHYSICAL ENVIRONMENT
A review of trends in the natural and built environment

This paper reflects the increasing realisation that health and the environment are inextricably linked. Stephen Palmer addresses the links between health and the environment in terms of, amongst others, globalisation, and trends in leisure activities, housing and air quality. The paper advocates an evidence-base linking environmental hazards to health, resulting in an integrated policy approach involving the public.

Stephen Palmer was appointed to the Mansel Talbot Chair in Epidemiology and Public Health, University of Wales College of Medicine, in 1998. Previously, he was head of the Communicable Disease Surveillance Centre (CDSE) (Wales). He is currently Chairman of the Welsh Collaboration for Health and the Environment.

POLICY FUTURES FOR UK HEALTH

Edited by Charlotte Dargie

This paper is part of a series written for the Policy Futures for UK Health Project, which examines the future environment for UK health, with a time horizon of 2015. The full series is listed below.

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Technical Series

NO 2 THE PHYSICAL ENVIRONMENT
A review of trends in the natural and built environment

Stephen Palmer

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Stephen Palmer

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Charlotte Dargie

FOREWORD

Since its inception the Nuffield Trust has identified individuals and subjects that would impact on health and health care policy in the United Kingdom, with notable examples being *Screening in Medical Care* [1], Archie Cochrane's *Effectiveness and Efficiency: Random Reflections on Health Services* [2], Thomas McKeown's *The Role of Medicine: Dream, Mirage or Nemesis?* [3], David Weatherall's *The New Genetics and Clinical Practice* [4] and Alain Enthoven's *Reflections on the Management of the National Health Service* [5].

In keeping with tradition and reflecting the more complex issues in health and health care policy today, the Nuffield Trust established a Policy and Evaluation Advisory Group (PEAG), supported by the appointment of a Nuffield Trust Fellow at the Judge Institute of Management Studies at the University of Cambridge, to provide a research and intelligence capability for the Trust.

The Policy Futures for UK Health Project stems from the work of PEAG. It involves examining the future environment for UK health, with a time horizon of 2015. The first environmental scan has resulted in a series of 10 technical papers, which cover the following areas[1]:

1. The Global Context
2. The Physical Environment
3. Demography
4. Science and Technology
5. Economy and Finance
6. Social Trends
7. Organisation and Management
8. Workforce
9. Ethics
10. Public Expectations

Each paper in the series is a stand-alone piece, but has also been used by the project to derive an overview report, which focuses on policy assessment in the light of the environmental scan. Entitled 'Pathfinder Report', the overview report is published separately and will be subject to external consultation[2].

The Policy Futures for UK Health Project and the work of PEAG are ongoing. Further reports and publications will appear in subsequent years. The technical papers will also be revisited and different subjects will be tackled.

The strength of the technical series is in providing a context for analysing health and health care policy for the United Kingdom. Each author has produced an independent piece of work that analyses trends and issues in their subject area, focusing on 2015. The papers enable one to read across the issues, in order to provide a general analysis of health and health care policy, which is lacking in the highly specialised debates that dominate the health world today. They have formed the basis for consultation and discussion as part of the Policy Futures for UK Health Project.

Finally, the Trust is grateful to the members of the PEAG, to Professor Sandra Dawson and Pam Garside of the Judge Institute of Management Studies and to the authors of the 10 technical papers. A particular thanks due to Dr Charlotte Dargie, Nuffield Trust Fellow at the Judge Institute of Management Studies, the author of the Pathfinder report.

John Wyn Owen CB
July 1999

ENDNOTES

1. *Screening in Medical Care: Reviewing the Evidence* A collection of essays with a preface by Lord Cohen of Birkenhead (Oxford: Oxford University Press for the Nuffield Provincial Hospitals Trust, 1968).
2. AL Cochrane *Effectiveness and Efficiency: Random Reflections on Health Services* (London: Nuffield Provisional Hospitals Trust, 1971).
3. T McKeown *The Role of Medicine: Dream, Mirage or Nemesis?* (London: Nuffield Provisional Hospitals Trust, 1976).
4. D Weatherall *The New Genetics and Clinical Practice* (London: Nuffield Provisional Hospitals Trust, 1982).
5. AC Enthoven *Reflections on the Management of the National Health Service: An American Looks at Incentives to Efficiency in Health Services Management in the UK.* (London: Nuffield Provincial Hospitals Trust, 1985).
6. S Williams, S Michie and S Pattani *Improving the Health of the NHS Workforce* (London: The Nuffield Trust, 1998).

Each of the papers in the series is available from the Nuffield Trust.

[2] C Dargie *Policy Futures for UK Health: Pathfinder* (London: The Nuffield Trust, 1999). The Pathfinder Report is for wide consultation and invited comment. You can email your comments to policyfutures@jims.cam.ac.uk. You can also send your comments to Dr Charlotte Dargie, Nuffield Fellow in Health Policy, The Judge Institute of Management Studies, Cambridge University, Cambridge, CB2 1AG. You can also find this Pathfinder Report along with other technical papers in the Policy Futures series at the Nuffield Trust website: http://www.nuffieldtrust.org.uk. Please respond with your comments by Friday 19 November 1999.

ABBREVIATIONS

ACMSF	Advisory Committee on the Microbiological Safety of Food
BSE	bovine spongiform encephalopathy
CO	carbon monoxide
DETR	Department of Environment, Transport and the Regions
DoH	Department of Health
GEENET	Global Environment Epidemiology Network
GELNET	Global Health and Environment Library Network
GEMS	Global Environment Monitoring System
GERMON	Global Environmental Radiation Monitoring Network
HIV	human immunodeficiency virus
IARC	International Agency on Research of Cancer
ICNIRP	International Commission on Non-Ionising Radiation Protection
ICUs	intensive-care units
IPHECA	International Programme on the Health Effects of the Chernobyl Accident
ITP	International Thyroid Project
IV	intravenous
NO2	nitrogen dioxides
NO_x	nitrogen oxides
O3	ozone
PM10	fine particles in air that are <10mm in diameter
ppm	parts per million
SO2	sulphur dioxide
UK	United Kingdom
UNEP	United Nations Environment Programme
USA	United States of America
UV	ultraviolet
VOC	volatile organic compound
VTEC	Verocytotoxic E.coli
WHO	World Health Organisation

SUMMARY

Trends

The use of health impact assessments will become widespread in government, agencies and local authorities.

Globalisation of trade and travel, global warming and social trends, among others, will ensure that new infectious diseases will emerge or re-emerge, often through foodborne routes.

Improvements in housing and town planning are likely to be a major focus in tackling inequalities in health, but the disposal of waste and use of contaminated land will be a growing problem.

Increasing numbers of chemicals entering the global market will lead to increasing exposure and fear of health effects fuelled by an increasing ability to measure biomarkers of exposure.

Ozone depletion and trends in leisure activities will continue the trend in skin cancers.

Policy issues

The evidence base for assessing potential environmental hazards to health, and the capability for cross-disciplinary public health research in the UK, is weak.

There is a lack of a clear leadership role at local level in dealing with the health impact under the Environmental Protection Act 1990.

Predicting the complex interactions of environmental and social health determinants requires new sophisticated methods of health impact assessment.

Traditional public health infrastructures (e.g. water treatment systems to prevent emerging infections) must be sustained.

The public must be brought into partnership in developing risk assessment approaches and determining policy consequences.

BACKGROUND AND SCOPE

The environment has been defined as 'All that which is external to the individual human host. It can be divided into physical, biological, social, cultural etc any or all of which can influence health status in populations' [1]. Human activities such as agriculture, industry, use of natural resources and production of waste, urbanisation, health care services, lifestyle trends, education, travel and religion are influenced by, and in turn can influence, the biological and physical environment. Health is inextricably linked to the complex interactions between these human activities and the environment. That interaction has been represented in a model, based on a model published by the World Health Organisation (WHO) Commission on Health and Environment [2] (see figure 1).

A conceptual model relating hazards within the environment is also given (see figure 2). In this model the population, which is made up of people with a range of genetic susceptibilities to environmental factors, is living within both a physical and social environment. Their probability or risk of developing disease, which can be measured epidemiologically, depends upon their exposures to biological, chemical and physical hazards within natural ecosystems and the built environment. Stages towards disease end points may be measured through biomarkers of health effects. Within this system it is also important to note that social factors may also influence risk of disease, as well as perceptions of risk (e.g. living near a landfill site that leaks chemicals into the environment), which may not match the epidemiological measure of risk but 'where people define situations as real, they are real in their consequences'[a].

It is clear from the model that policy in many areas, from transport to energy to housing, and not just health care, will affect health states, and it is the United Kingdom (UK) government's intention to evaluate the health impact of all policy areas [2]. However, risk assessment methods for health impact assessment of the complex interactions of environment and social influences, are in their infancy [3]. A framework has been used by WHO to distinguish a hierarchy of influences (see figure 3).

However, there is a fundamental general problem in the lack of true cross-disciplinary research and consequently a sparse evidence base for health impact assessment. By 2015 we should expect the evidence base to be considerably stronger, and that understanding these interactions will be well developed, since environment and health issues will continue their steady rise to become a dominant theme in health policy development.

An added complication in developing health impact assessment approaches to policy development is the growing body of evidence suggesting that environmental factors may not operate on humans equally throughout the life course [4]. Environmental factors operating in the prenatal period may set the pattern for adult health [5]. If this is the case, major policy implications will

[a] Quote attributed to Sandra Dawson at a meeting in Cambridge.

flow, including increasing emphasis on nutrition of women before and during pregnancy, lifestyle factors during pregnancy (e.g. smoking and drinking) and infant nutrition.

In adult life the socioeconomic factors in inequalities in health have now been linked closely to relative differentials in income [6] and to psychosocial stress, in turn related to unemployment, social integration, social inclusion and the workplace environment. Policy makers will therefore need to consider the operation of environmental factors not only at the individual level, but at the community level and within specific settings such as the workplace.

The field of environment and health is so large and complex that WHO have set up several 'health and environment' information networks including:

- Global Health and Environment Library Network (GELNET) [7]: A network of libraries and documentation centres throughout the world, dedicated to act as a source for information on health and the environment. Currently there are 125 member libraries in 84 countries.
- Global Environment Epidemiology Network (GEENET) [8]: An important means of communication and collaboration for professionals working on the health effects arising from exposure to environmental hazards. Specifically, GEENET aims to increase the national capacity of developing countries to secure environmental health by strengthening education, training and applied research in health effects assessment and environmental epidemiology.

A measure of the scale of issues in this field is that a search of the Department of the Environment, Transport and the Regions (DETR) website [9], for 'predicting trends in environment and health', yielded over 1,000 government documents.

TRENDS IN CHEMICAL, PHYSICAL AND BIOLOGICAL HAZARDS

Air

There is a growing body of evidence linking air quality with health. Atmospheric pollution has long been known to cause respiratory symptoms, but recent studies suggest that the risk of cardiovascular disease may also be increased, and the presence of certain carcinogens in the air is another cause of concern. Outdoor air quality will be more closely monitored by local authorities in the future. Future UK pollutant levels can be predicted in the light of current trends in the sources of these substances.

POLICIES

Air quality is determined by human activities and the weather. It can therefore be partly controlled by legislation. In 1997 the UK National Air Quality Strategy [10] was published, giving objectives for ambient air quality until 2005 and beyond. These objectives were given statutory status (except for ozone), local authorities being required to monitor progress in achieving them. Because pollutants travel across national boundaries, international co-operation is important. European Union legislation lays down legally binding limits for several pollutants, to be achieved by 2005 and 2010, and various Directives will give a further degree of control. In consequence of these and other measures, several of the Air Quality Strategy's objectives should be attained earlier than expected, and more ambitious targets are now proposed [11].

PARTICLES

During the next ten years the atmospheric concentration of fine particles (PMio) is expected to decline [10]. By about 2010, vehicle emissions (the major source for most people) should decrease to half or even a third [11] of the 1995 levels; secondary aerosol formation and other emissions will also decline. Consequent health benefits are likely, since daily particulate concentrations are related to deaths [12][13] and hospital admissions for respiratory [14] and cardiovascular diseases [15], although the effect on life span is uncertain [16]. From 2010, however, vehicular emissions will rise due to greater traffic activity.

OXIDES OF NITROGEN

Road transport currently accounts for 46 percent of all emissions of nitrogen oxides (NO_x). The fitting of catalytic converters to new cars and other changes will cause a halving of these emissions from 1995 to 2010, and a consequent fall in ambient concentrations. Figure 3 shows predicted emissions and the peak nitrogen dioxide (NO2) levels that would occur in the weather conditions that produced the 1991 pollution episode in London, given projected trends in vehicles [10] (see figure 3). Revised estimates suggest that the decline in emissions may be even greater and more prolonged, attaining less than 30 percent of the 1995 level by 2015 [11]. Episodes of high NO2 are associated with increased mortality and morbidity from cardiovascular and respiratory diseases [17] [18] so there should be real health benefits from these changes.

OZONE

Ozone (O3) is produced by the interaction of NO_x and volatile organic compounds (VOCs) in the presence of sunlight. Since VOC emissions are also expected to fall (by about 35-40 percent from 1995 to 2010), O3 concentrations should decrease too [10][ll]but predictions are difficult, partly because of the complex nature of these reactions and partly because of transfer of O3 from the stratosphere and elsewhere. Health benefits are likely, since daily O3 levels are associated with numbers of deaths and (particularly in the elderly) hospital admissions for respiratory disease.

CARBON MONOXIDE

Road transport currently accounts for nearly 75 percent of emissions of carbon monoxide (CO). Changes to petrol-engined vehicles will reduce CO emissions and atmospheric concentrations, so that Birmingham city centre (for example), with a maximum 8-hour running average of 6.9 ppm (parts per million) in 1995, will have levels of 1.7-5.0 ppm in 2010 [10]. Beneficial health effects may be expected, since daily CO is associated with a number of deaths and hospital admissions for cardiovascular diseases [16].

SULPHUR DIOXIDE

Sources of sulphur dioxide (SO_2) are dominated by a few emitters, so that, in 1995, 44 percent of all SO_2 emissions arose from nine power stations. Plumes from smaller plants can cause high concentrations locally in certain weather conditions. By 2010, technical improvements in power stations, plus the increasing use of natural gas in the manufacture of electricity, should have reduced SO_2 emissions to 36 percent of their 1995 level [10]. Associations between daily SO_2 concentrations and mortality [13] suggest that there will be some benefit to health.

BENZENE AND 1,3-BUTADIENE

Petrol vehicle exhaust accounts for two-thirds of the emissions of benzene and 1,3-butadiene; the former is a minor ingredient of petrol, while both are produced by petrol combustion. The use of catalytic converters is expected to reduce emissions, which by 2010 should be about 40 percent and 25 percent respectively of their 1995 levels [10] or even lower [11]. Both compounds are carcinogens, associated with leukaemia and similar disorders, so that any reduction in exposure is likely to reduce the population risk of these very serious diseases.

ASBESTOS

The removal of asbestos from buildings may have increasing profile as the incidence of mesotheliom increases due to historical exposure.

Food

The UK Governments' Advisory Committee on the Microbiological Safety of Food (ACMSF) [19] has been reviewing foodborne safety issues of emerging national importance. Amongst the subjects considered in the last few years are:

VACUUM PACKAGING

The increasing range of novel food processing methods has raised concern about a new threat from botulism. An Industry Code of Practice was published in 1996. Implementation of the Code in Small and Medium Enterprises is considered difficult and close monitoring of new processes is required.

VEROCYTOTOXIC E.COLI

Extensive surveys of food animals are being planned which will reveal the true prevalence of infection in herds and flocks, and the extent of contamination of carcasses. Both training of food handlers and inspection systems of food premises are perceived to be weaknesses in the prevention of verocytotoxic E.coli (VTEC). The potential exists in the UK for further significant outbreaks which continue to attract huge media and public interest. Hazard Analysis Critical Control Point-based approaches in all sectors of the food industry are strongly recommended. The continuance of the sale of raw milk in England and Wales is an additional risk.

CAMPYLOBACTER

The incidence of this most common enteric bacterial infection continues to rise year on year. The epidemiology is poorly defined. New typing systems introduced in 1997 may elucidate its epidemiology and lead to new recommendations for control. Currently, foodborne infections from poultry meat are generally considered the major route for human infection.

POULTRY MEAT

Poultry meat is heavily contaminated with Campylobacter and salmonella. Commercial pressure to reduce the price of meat is presented by the industry as a barrier to implementing control programmes on farms and abattoirs such as those proven to be successful in Sweden.

SALMONELLA AND EGGS

The pandemic of salmonella entertidis in the 1980s was probably due to transovarian transmission in the breeder flocks and subsequently in laying flocks. Despite the flock testing and slaughter programme, the incidence of contamination of eggs in the UK and Europe was unchanged from the late 1980s. The incidence of human infection increased until 1997, but since then there has been a sharp, though unexplained, fall in incidence.

FOODBORNE VIRAL INFECTIONS

New diagnostic techniques are predicted to establish Small Round Structured Viruses infection as the commonest cause of enteric illness, which are often food- or waterborne. Of particular interest is the possible consequence of sewage sludge disposal on land and contamination of fruit and vegetables.

Water

Although typhoid and cholera, which were common in the rapidly developing conurbations of the nineteenth century, are not now transmitted via public water supplies in developed countries, concern continues that even treated drinking water passing current standards is a significant cause of gastroenteritis. Following a study in Laval, Canada, it was suggested that one-third of gastroenteritis episodes could be attributed to consumption of treated drinking water [20]. This study employed a randomised trial involving reverse osmosis units fitted to a randomly selected group of households. It generated much international interest and is the subject of follow-up investigations. Modern water supply systems also have the potential to operate as highly effective pathogen delivery systems following the rare events where the multiple barriers protecting the public are breached or the supply is contaminated following treatment. This potential has been realised in disease outbreaks associated with public water supplies involving E.coli 0157 [21] and Cryptosporidium [22].

Cryptosporidium presents by far the most pressing current concern because of its ability to resist terminal disinfection with chlorine [23], and because the infectious dose is very small. Water treatment to ensure the physical removal (rather than chemical inactivation) of the oocysts is the principal means of control. However, all engineering systems are subject to failure due to human error, extreme events and/or inappropriate operating procedures. Combinations of these factors have caused cryptosporidiosis outbreaks in the developed world. For example, a recent expert group report listed some 25 UK outbreaks of cryptosporidiosis associated with public drinking water supplies [23].

The UK Government has responded to this problem by new 'draft' regulations requiring water companies to undertake daily testing for Cryptosporidium oocysts on treated waters [24].

Infectious risks from exposure to recreational waters have been well documented. Marine, freshwaters and chlorinated pool waters have all been implicated in published reports of gastrointestinal and non-enteric illnesses [23][25][26][27]. This reflects on the adequacy of existing water quality standards for surface recreational waters; new guidelines are now in preparation and will be published in 1999 by WHO.

In addition to the infectious illnesses associated with water, many chemical constituents, generally within current standards compliance ranges, have from time to time been associated with adverse health outcomes - for example, aluminium and Alzheimer's disease [28][29], nitrate and stomach cancer [30], chlorine [31] and water hardness and coronary heart disease [32]. The scientific literature in this area is extensive. However, most studies in this area are 'ecological' studies which can suggest hypotheses, but usually the presence of many confounding factors makes the aetiological contribution of water difficult to assess. Private water supplies often do not comply with current standards and local episodes of chemical induced illness, e.g. from organophiophosphate insecticides, may well go undetected.

Solid wastes, soil contamination and chemical exposure

CONTAMINATED LAND AND WASTE DISPOSAL

The importance of this area of concern has been highlighted by the government's policy to develop brownfield sites for commercial and domestic purposes in preference to greenfield sites.

Legislation was first proposed in the Environmental Protection Act of 1990 to attempt to identify and, where possible, remedy land that was contaminated. The proposed legislation proved to be very controversial and was never brought into operation by Parliament. The Environment Act of 1995 amended the proposed system for the identification and remediation of contaminated land. However, the legislation was not brought into force at that time because of the financial implications. It is now proposed to bring the legislation into force in June 1999. The Act places the responsibility on local authorities to inspect their districts from time to time in order to identify contaminated land, and to decide whether or not to designate such land as a special site.

In the older industrial areas of the UK there are many sites that could be described as contaminated land, including current or finished waste disposal sites, which are either near centres of population or are required for building of new dwellings etc. The possible (though not yet proven) risks to the health of the public living or working on or near such areas have been highlighted by research on the incidence of congenital malformations in mothers living within 7 km of landfill waste sites [33][34]. Other studies have suggested a link between landfill sites and self-reported headaches, sleepiness, respiratory symptoms and gastrointestinal problems [35][36][37].

Experience at local level suggests that regulatory authorities, under the specific legislation they enforce in the Environmental Protection Act of 1990, do not see it as their responsibility to deal with the potential effect of the waste tips on the health of the public. The risk assessment processes that are used are more concerned with the effect on the ecosystem generally. The lack of an accepted health impact assessment methodology is a major weakness, since there is as yet no systematic and objective ways to deal with public fears.

CHEMICAL HAZARDS

It is estimated that more than 600 new chemical substances enter the market place each month [38], adding to over 11 million known substances, of which 60-70,000 are in regular use [39]. Adequate toxicology exists for only 2-3 percent of these [40]. As industrialisation of developing economies progresses, the use of chemicals and environmental pollution will increase so that humans will be exposed increasingly both acutely and chronically to a wide variety of chemical agents. Routes of exposure are air, water, soil and food and absorption occurs through the respiratory and alimentary tract as well as through skin.

We anticipate that new methods will become available routinely to assess exposures. Analysis of tissues and body fluids for chemicals or their metabolites, enzymes or the products of a molecular interaction (biomarkers) may be used in quantitative risk assessment of exposure [41][42]. Biomarkers may be used in hazard identification, exposure assessment and to associate a response with the probability of a disease outcome. Population groups 'at risk' may be identified by deviations from mean values for biomarkers or effects. Also biomarkers indicative of genetic or acquired sensitivity to specific chemicals may be used to identify susceptible individuals. Of all potential health risks the most emotive is chemical genotoxic carcinogenesis. Urinary or blood concentrations of several chemicals known or suspected to be carcinogenic (e.g. benzene and tetrachloro ethylene) have found use as biomarkers in an occupational setting. More recently, sensitive techniques based, for example, upon immunochemical methods have been developed for the detection of carcinogen-modified DNA bases (adducts).

To date biomarkers have been used primarily in biological monitoring programmes in the field of occupational health. The expansion of their use to monitor exposures of a general population to a variety of environmental toxins involves a number of issues. An ever-increasing variety of biomarkers is being made available and in many instances the accuracy, precision and quality assurance of the analytical procedure for measurement of the selected biomarker is inadequate. Once analytical considerations are satisfied then the specificity and sensitivity of biomarkers as measures of the exposure and predictors of health outcomes need to be known. This information is generally lacking except for a few well-characterised toxicants. Progress in the above areas will permit specifically designed longitudinal epidemiological studies with valid measures of exposure, biomarker concentrations and health outcomes to facilitate risk assessment. The use of validated biomarkers of exposure will increase the power of epidemiological studies compared to those designed to examine only health outcomes. Recent knowledge on the genetic basis for individual susceptibility will increase further the power of epidemiological study since populations may be stratified according to their genotype.

A major issue is the systematisation of biomarker research and the requirement for the development of large databases containing biomarker measurements from, for example, breast milk or blood. In this way data relating to exposures (acute or chronic) of specific toxicants may be generated in a standard format for epidemiological purposes.

The number of ethical issues involved in such general biomarker work programmes possibly exceed even those associated with screening. Emotional, legal and social aspects are involved and the right of participants to intelligible information on risk must be married to the use of the data for purposes of protecting the public health.

Radiation

SOLAR RADIATION

Ultraviolet (UV) radiation is the major cause of the rapid rise the incidence of skin cancer in the UK over the last 30 years; eight out of 10 cases are potentially avoidable by avoiding exposures. However, ozone holes have been detected over both the northern and southern hemispheres and will persist for many years to come. Corresponding increases in UV intensities will result in more skin cancers, accelerated skin ageing, cataract and other eye diseases, and may have an adverse effect on a person's ability to resist infectious diseases, or indeed may compromise the effectiveness of vaccination programmes.

INTERSUN [43] is a collaborative effort between WHO, the United Nations Environment Programme (UNEP), the International Agency on Cancer Research (IARC), the International Commission on Non-Ionising Radiation Protection (ICNIRP) and appropriate specialist agencies at the international and national level. It encourages further research into the effects on people from exposure to UV and supports national health care programmes to prevent UV-induced diseases.

IONIZING RADIATION

In general, the total biological effect of ionizing radiation will depend on:

- Total dose
- Type of radiation
- Age at exposure
- Tissue volume exposed
- Time interval of exposure
- General state of health
- Stage and rate of cell division of exposed tissue.

The model of best fit for the dose response is a linear relationship with no lower threshold and with a flattening of risk at extreme dosage. The temporal patterns of risk are not fully evaluated since there have only been a limited number of acute exposures and a limited time since events such as Hiroshima and Nagasaki.

Radiation-induced leukaemias are seen soon after exposure with increased risk in the young, over a 25-30 year period [44]. Solid tumours develop much later and the increased cancer risk persists for life. In addition, the presence of other carcinogens such as tobacco increases cancer risk, the effects being additive [44] [45]. The range of cancers seen in exposure victims are the same as those seen in the rest of the population, i.e. there are no specific radiation tumours. They appear with the same age profile as non-radiation-induced tumours - apart from leukemia - but with increased incidence. These features of radiation carcinogenesis make epidemiological studies difficult to conduct.

Much work is still needed in this area to establish that results extrapolated from disaster victims can be applied to others exposed to lower doses. Studies on the exposure of workers in the nuclear industry in Canada, UK and USA have found that the risks predicted from acute exposures are within the range seen in those exposed at lower doses [46], but this work needs to be continued.

To monitor radioactivity in the environment, WHO have set up the Global Environmental Radiation Monitoring Network (GERMON), a network of WHO collaborating centres and liaison institutions. A global map of national and man-made radioactivity levels in the environment is being prepared. The Chernobyl accident continues to be followed up. Building on the results of the activities carried out within the framework of the WHO International Programme on the Health Effects of the Chernobyl Accident (IPHECA), the International Thyroid Project (ITP) and a series of the International Agency on Research of Cancer (IARC) are piloting projects aimed at evaluating the feasibility and testing of different approaches for the epidemiological monitoring of exposed populations. The priority areas are:

- thyroid diseases (Thyroid Project)
- accident recovery workers or 'liquidators' (Accident Recovery Workers Project)
- dose reconstruction (Dose Reconstruction Project).

Under these activities a standardised 'Dose Reconstruction Project' protocol has been developed. The development of an 'Accident Recovery Workers Project' protocol is also in progress. A network of WHO collaborating centres for in-depth investigation of the cause of the thyroid cancer outbreak after the Chernobyl accident has been established.

NATURAL RADIATION EXPOSURE

Radon gas accounts for about 55 percent of our natural exposure to radiation. It is a colourless, odourless gas that comes from the decay of uranium and is found in nearly all soils. Levels vary with place of residence and are high in some parts of the UK, e.g. Cornwall, and with certain types of construction material e.g. stone-built houses. Radon gas seeps through cracks and holes in foundations from the ground up and is trapped by poorly ventilated buildings. Breathing large amounts of radon gas is estimated to be the second largest cause of lung cancer in the USA, and has been estimated to cause 7 percent of lung cancer deaths in Germany [47].

Much of the work relating to the health consequences of radon exposure has been carried out on mine workers in Sweden who have been shown to be a reliable model for estimating residential exposure risk [48]. The cancer risk in miners is related to exposure rate and the presence of other carcinogens such as arsenic. However, more work is required on miners with below-average exposure rates so we can develop a robust epidemiological model for residential radon risk. This view is echoed by others [49] who call for caution in the interpretation of risk estimates put forward by the Environmental Protection Agency in the USA, because of confounding factors such as residential mobility and smoking behaviour. Large variations in residential radon concentrations, at its greatest in basements, have been found. However, reduction of the risk of lung cancer by radon reduction was estimated in one study to be only the equivalent of reducing smoking prevalence by 0.5 percent [50].

ELECTROMAGNETIC FIELDS

Extremely low-frequency magnetic fields Feychting *et al.* [51] report no known mechanisms by which magnetic fields can play a role in cancer but note that it is a consistent finding that there is an association between extremely low-frequency residential magnetic fields and cancers, especially leukaemia in childhood. However, many of the epidemiological studies are methodologically flawed [52][53][54]. There is some evidence that magnetic fields can affect cell membranes [55], and in the occupational setting there is evidence that increasing exposure to steady magnetic fields decreases the leukocyte count and monocyte percentage in workers [56]. In a large-scale study of 138,905 men employed in electrical companies in the USA and Canada, Savitz and Loomis [57] found that cancer mortality rose slightly with increasing magnetic field strength. Leukaemia mortality was not associated with exposure, except for electricians, but brain tumours were elevated and related to the duration of work in exposed jobs.

This new work is going to become more and more relevant with the increasing exposure of individuals to magnetic field flux, e.g. in magnetic resonance imaging, and the increasing use of electric motors, e.g. in personal transport.

Risk ofradiofrequency and microwave radiation More and more attention is being paid to the possible health hazards associated with mobile phone use. However, the health consequences of increased exposure to either pulsed electromagnetic radiation or amplitude-modulated (AM) radio-frequency waves is as yet inconclusive and unclear [5 8] [5 9]. Mobile phones emitting pulsed high-frequency electromagnetic fields caused a modulated response pattern of brain activity [60], but the exact mechanisms for this, and the long-term consequences, are unclear.

As we move to a more global village, we rely more and more on immediate communications and access to world wide news and information, combining mobile phone technology with the power of the personal computer. Both rely on and emit radiation. The long-term health effects are not yet understood and further research is required urgently [61] [62].

Noise

There is growing concern over the health effects of environmental noise. Research evidence is accumulating slowly but a recent review showed that increases in road traffic, aircraft and contamination may result in sleep disturbance and poor school performance [64], and possible association with hypertension and ischaemic heart disease. There is concern that leisure noise at concerts and discos can lead to temporary noise-induced hearing loss [64][65] [66][67]. High noise levels in intensive-care units (ICUs), particularly neonatal ICUs, may cause long-term hearing loss in children [68].

Infectious diseases

The emergence of new diseases (e.g. bovine spongiform encephalopathy [BSE] and hantavirus) and the reemergence of once controlled diseases (e.g. cholera in South America and tuberculosis in the USA) has received global interest in the last seven years [69]. The causes of these emergences are complex and are due to the interaction between the host, the agent and the environment. Changes in the physical (global warming and El Nino) and the built environment (urbanisation) are important. In part, societies have reaped the consequences of the neglect of traditional public health infrastructures such as sewage systems and water supplies [70]. The collapse of organised public health systems, as in the former Soviet Union, has led to migration and epidemics of diphtheria and tuberculosis. War and civil disruption continue to bring the classic plagues of the past, such as cholera in Rwanda, polio in Chechnya and typhoid in Bosnia.

In addition, changes in the social environment interact in important ways. For example, changes in sexual patterns in recent times, including the reduction in age of first sexual activity and increasing numbers of sexual partners, have enabled global epidemics of sexually transmitted diseases.

Key underlying factors [71] in the global epidemiology of sexually transmitted diseases are:

- lack of adequate medical services for diagnosis and treatment in developing countries
- poverty, leading to prostitution
- urbanisation and migration, leading to high density of sexually active young people, free from traditional cultural restraints
- male migration of work, leading to casual sex encounters
- war and social upheaval, leading to break-up of families, concentration of highly sexually active men and commercial sex workers
- low education levels in women, making them vulnerable to exploitation in cities
- sex tourism.

The increase in intravenous drug use has led to an epidemic of bloodborne diseases, including hepatitis B, hepatitis C, hepatitis D, hepatitis E, and human immunodeficiency infection (HIV). The global trade of intravenous drugs has exploited the youth culture and poor urban populations. Accompanying the globalization of markets has been the growth of international travel and tourism. Importation of exotic infections, with the threat that they may become epidemic, has been taken seriously by governments. The threat of Lassa fever spreading by the airborne route led to the institution of high-containment facilities and the development of public health guidelines. Inadvertent importation of infected mosquitoes in tyres has been identified as the cause of the spread of dengue.

The growth in international travel has also had a profound effect on the global spread of disease. The global spread of HIV within only a few years of its emergence in USA and Europe is directly attributable to business and tourist travel.

Policies in the criminal justice system have implications for emerging infections. Over-crowded prisons have been important sites for the spread of meningococcal disease into the community. High carriage rates build up in inmates, who then take infection out to the community on their release. In the USA, development of multi-resistant tuberculosis arose particularly in over-crowded prisons with inadequate medical care. Intravenous (IV) needle sharing is common in prisons and this has amplified hepatitis B, C and HIV epidemics in many countries. Policing policies also can have an effect on transmission. For example, willingness to allow anonymous exchange of IV needles and syringes at designated centres in the UK may have had a profound effect in preventing an epidemic in IV drug users in low endemic areas such as Wales.

If policy makers wish to contain and, ultimately, reverse the resurgence of infectious disease, they need to re-adopt, sustain and develop these effective interventions at a national and an international level. National infrastructures remain key to health policy. Health impact assessments of economic and social policies need to take emerging infections into account, especially in the global market. Formalised approaches may promote more reasoned consideration of topics such as food irradiation, which is usually unpopular with the public and, hence, the more demotic politicians, but may bring benefits in controlling foodborne infection.

The natural environment

Climate

The Intergovernmental Panel on Climate Change [72] has predicted a steady increase in the average world temperature of between 1° and 3.5°C over the next century. The UK DETR has established a series of linked research projects to predict these changes and their impact upon natural ecosystems, water resources, food supply and coastal areas. The ecological predictions over the next 50 years [73] are:

- the North Atlantic ocean circulation will slow down
- tropical forests in Brazil will die back and tropical grasslands will convert to desert or temperate grassland
- water stress will extend significantly
- crop yields will increase in high- and mid-latitude countries but decrease in low-latitude countries
- Africa will be worst affected by reductions in yield
- global mean sea levels will rise by 21cm in 50 years and over 20 million extra people will be at risk of flooding.

Concerns about the health impact of climate change [74] cover:

- increased mortality and morbidity due to climate-related disasters
- increases in the incidence of skin cancer in fair-skinned populations and increased frequency of eye lesions (cataracts) resulting from exposure to ultra-violet radiation through the depletion of stratospheric ozone
- health effects of geographic change in food production
- effects of changing patterns in migration of peoples (both short and long term)
- changes in the geographical distribution of infectious disease
- increases in the incidence of cardio-respiratory deaths resulting from increased urban air pollution, caused by the processes thought to be responsible for changing the way the world's climate processes fossil fuel combustion.

Whilst there may be positive health outcomes resulting from the increase in global temperatures - for example, decreased mortality from cold-related respiratory disease - the net public health impact of climate change will probably be negative. In addition, climate change will not be uniform geographically and the greatest burden of ill health may be from extreme events in areas already economically disadvantaged - for example, the recent flooding experienced in Central America.

Many of the health effects described above may be interactive. Extreme climate events, displacement of people, disrupted social structures and malnutrition are powerful driving forces for the emergence of infectious diseases. A recent example of Rift Valley Fever in Kenya and Somalia where unprecedented dry-season rains and floods were associated with the El Nino phenomenon has increased transmission of mosquito-borne zoonosis.

Changes in climate will affect all human infectious disease agents that reproduce outside their host (e.g. salmonella food poisoning) or have an infective environmental stage of their life history (e.g. helminths). In addition, zoonoses will be affected by any changes that occur in the species range and distribution of their animal hosts (e.g. plague, yellow fever).

Some of the diseases most sensitive to climatic change are those that are vector-borne. Increases in temperature will influence the epidemiology of vector-borne diseases by:

Extending their current altitude and latitude limits A study in Rwanda [75] indicated that future temperature increases would cause malaria to move to higher altitudes. Dengue, a viral mosquito-borne disease, has also been reported at higher altitudes in Mexico [76]. It is important to note that even a small increase in the altitude range of an infectious disease may translate into many hundreds of miles in latitude. Examples of climate-related changes in the latitude range of infectious diseases are: Mediterranean spotted fever occurring in Spain, Hantavirus pulmonary syndrome in the American Southwest and Ross River virus in Australia.

Extending their current seasonal range Increased temperatures would also affect the incidence of vector-borne disease in areas where the disease already exists through increasing the seasonal range. Since temperature speeds the development of the life history of ticks from larval to nymph to adult stages, rates of transmission of tick-borne infections such as Lyme disease and human granulocytic ehrlichiosis might therefore be increased. The frequency of blood meals in mosquitoes is similarly related to temperature. Thus higher temperatures facilitate transmission of mosquito-borne disease.

However, the existence of malaria-free areas such as Trinidad would indicate that control is possible despite climatic conditions favourable to the vector and parasite. Epidemiological surveillance of both the disease and the insect vectors, together with rapidly implemented control programs, are essential to identify and contain imported infection.

Wildlife

Conservation efforts are generally directed toward increasing the abundance and diversity of wildlife. However, increases in the kind of wildlife that acts as reservoirs of infection may increase prevalence of human disease. In the USA, changes in farming practices led to reforestation of large tracts of the eastern states and a large increase in the population of deer, which are the main host for the idoxides tick, the vector of Lyme disease. Expansion of residential suburbs into wooded areas has contributed to the emergence of Lyme disease as a major tick-borne infection.

The growing numbers of badgers have been implicated in the re-emergence of bovine tuberculosis in the UK. Urbanisation of foxes poses the threat of a spread of rabies in Europe. The increasing numbers of stray dogs in some countries has been the cause of a resurgence in hydatid disease. An increase in the number of deer mice, brought about by climatic extremes and bumper crops of pinion nuts, has been implicated in the emergence of hantavirus pulmonary syndrome in the American southwest.

Disruption of the ecology and loss of biodiversity

The building of the Aswan dam was predicted to increase the mosquito population and thereby potentially initiate epidemics of Rift Valley fever. This has occurred. Deforestation may facilitate the emergence of communicable diseases that were previously only present in limited epizootic or endemic foci. The Ebola virus and AIDS may both have emerged from small foci in tropical Africa. However, probably the greatest impact of the mass clearing of tropical rainforest for farming will be the decrease in genetic diversity, with the loss of potentially medicinal products.

The built environment

Urbanisation

Economic activities are centered mainly in cities, where economies of scale allow development of educational and health systems which, together with wealth creation, improve population health. Nevertheless, the growth of megacities is a major factor globally both in the emergence and re-emergence of infectious diseases, and in the creation of pollution and an environment of violence and injury.

Crowding increases human contact, and with it, opportunities for transmission of disease. This is compounded by social problems including drug addiction, alcoholism, poor services and prostitution. It is likely that in the future much of the predicted urbanisation will be largely unplanned, and consequently accompanied by a lack of basic infrastructure. The growth of the megacities is far outstripping the ability to create adequate water supplies and sewerage and much of the expansion is in the form of shanty towns and favellas. Sanitation, or the lack of it, continues to have a considerable impact on human health. In developing countries over 8 million children die annually from diarrhoeal diseases. In large older cities the failure to modernise sewerage systems may allow previously controlled diseases to re-emerge, as in the case of cholera in South America.

It is estimated that more than half of the world's households cook daily with biofuels or coal. The UNEP/WHO Global Environment Monitoring System (GEMS) has demonstrated that the worst indoor ambient conditions exist in developing countries. A number of epidemiological studies carried out in India and Africa in homes burning biomass fuels or in China burning coal have reported adverse health outcomes [77].

Indoor air pollution is also of concern in developed countries, particularly as there is a trend to fewer changes per hour of indoor air than there used to be due to increased insulation and energy conditions. Indoor exposure relates to CO, NO2 allergens (e.g. house mites), volatile organic compounds and aldehydes [78].

Housing

Political interest in the role of the built environment has been reawakened in the last few years as attention has focused on explanations for the large inequalities in health in the UK. However, poor housing and housing in poor environments (e.g. near landfill sites) have been linked to increasing levels of long-term illness, respiratory disease and psychological problems. But how much of the variation in health by area is due to contextual factors (where people live), as opposed to compositional factors (characteristics of individuals). Studies are only now being set up to address this question, seeking to unravel the direct effect of housing on health from the role of the character of the built environment in mediating community-level influences such as social exclusion and the fear of crime [79]. For example; a major growing problem is community safety on 'sink' estates where there is a downward spiral of fear and violence [80]. Public health policies to address the social causes will also need to take into account the design of housing estates and the accessibility to services, transport etc.

Some of the worst housing conditions are found in multiple occupancy houses in the private sector, many houses lacking smoke detectors and adequate escape from fire [80]. Poor housing conditions may encourage house dust mites and moulds by poor ventilation and dampness, and these factors during early childhood are associated with increased risk of asthma. Trends in housing policy aimed at reducing energy consumption (e.g. the Home Energy Conservation Act requires Local Authorities to plan for a 30 percent reduction in CO_2, mainly from space heating energy use) may have health effects, positively by improving heating for the elderly, and negatively by reducing ventilation, thereby increasing humidity and house dust mites, and by reducing indoor air pollutants such as CO, NO_2, volatile organic compounds and aldehydes, as well as allergens.

DISCUSSION

This review of environmental influences on health illustrates how complex the issues are for policy makers. Traditional models of health and disease have concentrated on the pathological process of transition between the health of specific human body systems and disease. This reductionist model of human health ignored for many years the complex interaction that takes place between people, their local environment and the collective influences of society on individual life chances.

Table 1 summarises the many ways human health is affected by the environment described in this paper (see table 1).

One thing is clear, the tangle of interactions between the natural, built and socioeconomic environments does not permit cause-and-effect relationships to be easily teased out, despite the pressure to develop health impact assessment approaches to policy. Potentially, policies in all areas, from economic policy to transport and housing, are major determinants of health.

The evidence base in most areas described is weak, even though the volume of literature is huge. Hopefully it will grow considerably in the next 10 years as new research initiatives are set up. The challenge for policy makers will then be to keep up to date with and critically appraise a rapidly increasing volume of research. Environmentalists and social policy analysts may argue that many measures are justified in their own right without the necessity to show a link to health. (Deforestation should be stopped for ecological reasons and not because of the threat from Ebola; good housing is a social priority even if there are no direct health effects.) However, there are areas, e.g. in urban renewal, where choices have to be made, and inclusion of physical and mental health relationships should be taken into account. As countries take forward

Agenda 21[a], there is an opportunity to include health in the ecological approach. This could, for example, address the debate over the desirability of out-of-town commercial centres, which are dependent on car ownership and may increase pollution, as well as social isolation, leaving degenerating town centres to be foci for violent crime. The balance between economic pressure and social consequences can be seen starkly in this example. In order to be able to balance these issues, cross disciplinary research should be supported. But even when causal relationships are clarified, the methods for relating intersecting causes are not well developed. Further work is urgently needed to enable policy makers to model environmental, social and health data together.

It is difficult to quantify the risks from environmental hazards. The potential harm caused by an epidemic of Ebola or Lassa fever was considered to justify considerable investment in high-risk-category containment centres, but it now seems that the probability of a spread from imported cases to the general public is very small indeed. Huge attention has been given to the problem of outdoor air pollution from traffic and energy use, but the health effects, though real, are small when compared to the effect of smoking; anyway, outdoor and air quality in the UK is improving.

Trends in indoor air pollution are less clear and may be influenced by energy conservation and 'affordable warmth' housing policies of local government. Trends in foodborne disease are also difficult to predict. The fall in salmonella infection since 1998 was not anticipated and cannot yet be attributed to successful control measures. The increasing globalisation of trade and the increasing range of processing methods keeps open the opportunity for new (e.g. cyclosporosis) and re-emerging (e.g. botulism) foodborne disease. Trends in sewage disposal in the UK, with increasing use of agricultural land for disposal of human sludge, raises the possibility of foodborne infections from viruses surviving in the sludge. Formal risk assessments are only just beginning to be used to evaluate such potential threats.

The increasing numbers of new chemicals entering the global market has raised the fears of health effects of planned and accidental exposures. The health effects of most of these chemicals are not known, but public anxiety is high, especially in relation to waste disposal. We predict that an increasing capability to measure biomarkers of exposure will fuel public concern over the longer-term potential health effects (e.g. cancers) from chemical exposures. Policies to built housing on brownfield sites may exacerbate this problem.

In order to retain public confidence in risk assessment it is now clear that the public must be included in the assessment process. Transparent systems for modelling complex environmental, social and health data of high quality need to be developed. The initiatives to set up Health Action Zones could offer a context in which to engage the public in a joint health impact assessment

[a] The United Nations Program of Action for Environment and Development agreed upon at Rio de Janeiro in 1992.

process. Even if there is a lack of quantitative data, a qualitative approach may be very powerful.

FIGURES

Figure 1

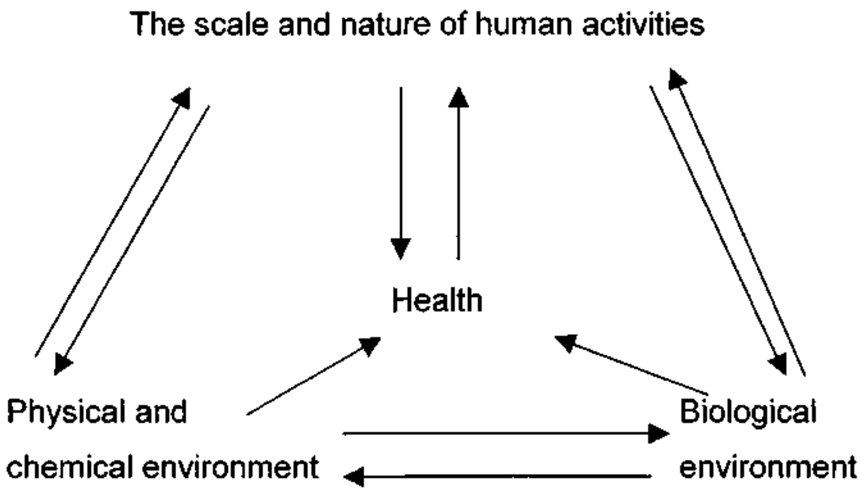


Figure 2 Environment and the public health

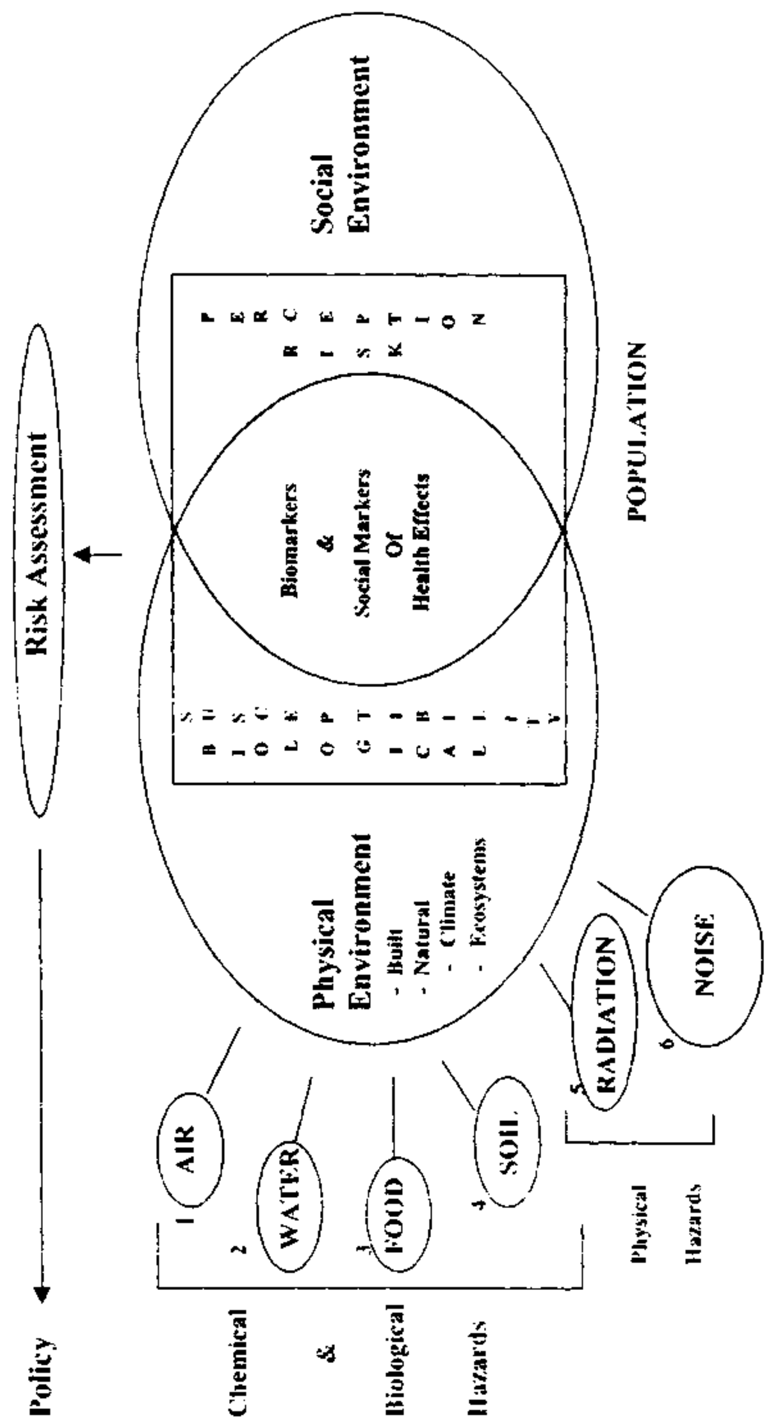


Figure 3 Hierarchy of environmental influences on health

driving forces (e.g. population growth)

↓

pressure (production, consumption and water release)

↓

state (e.g. pollution levels)

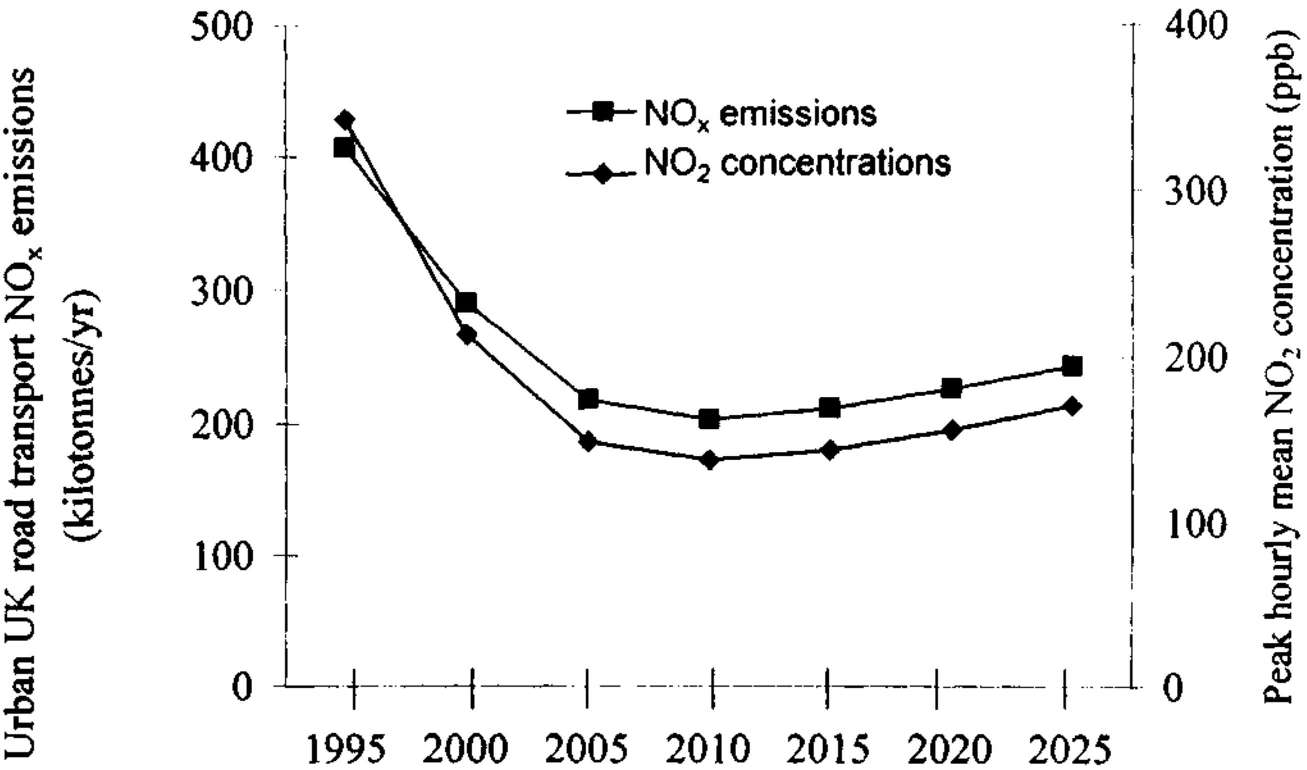
↓

exposure

↓

effect

Figure 4 Urban UK road transport NO_x emissions (kilotonnes/yr)



Urban box modelling of the December 1991 pollution episode
(from the UK National Air Quality Strategy)

Table 1 Environmental impacts on health

Impact of natural environment on humans	Impact of humans on the environment	Impact of new and old technologies
Solar radiation	Global climate change due to greenhouse gas emissions	The direct effects of car exhaust emissions on health
Natural background radiation	Change in land usage and loss of natural foliage and fauna - deforestation, arable land usage, soil erosion and animal husbandry practices	Modern agricultural methods - battery farming and salmonella, changes in the rendering process and BSE
Climate change		Land, water and air contamination with chemical and nuclear wastes
The El Nino phenomena	Loss of biodiversity	New chemicals introduced into the environment
Emerging infectious diseases and zoonoses	Urbanisation and impact of the built environment on air quality, water supplies, food production and preparation, waste disposal, contamination	Biomarkers and potential or proven carcinogens
	The close proximity between humans and animals	Exposures to new forms of radiation such as mobile phones, power cables, medical imaging, x-rays, magnetic ultrasonic and noise pollution
	The direct effects of housing on health	

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