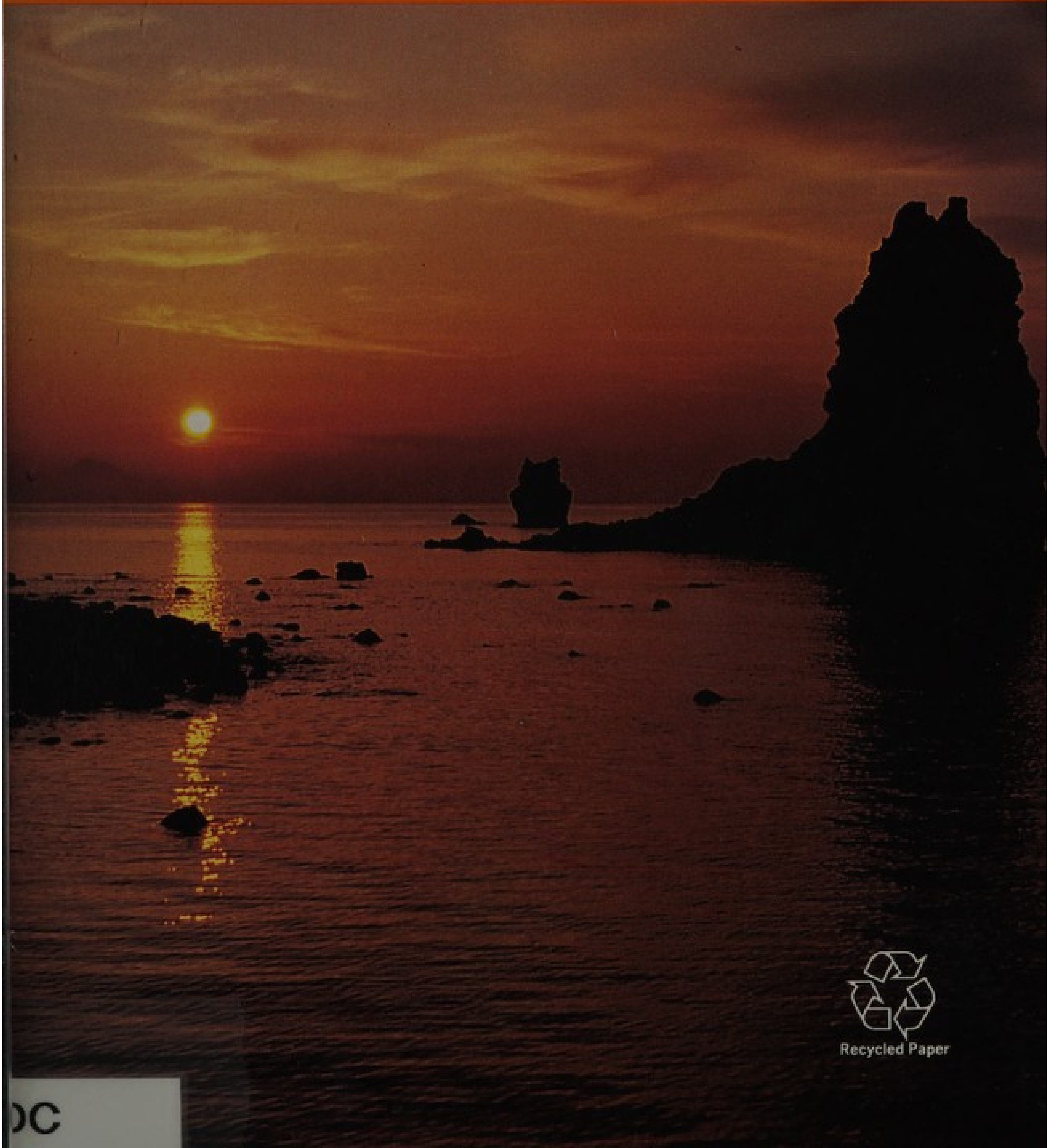
Department of the Environment

Expert Panel on Air Quality Standards

Particles



Department of the Environment

Expert Panel on Air Quality Standards

Particles

London: HMSO

ISBN 0 11 753199 5

Previous reports by the Expert Panel on Air Quality Standards

1st report	Benzene	February 1994	ISBN 011 752859 5
2nd report	Ozone	May 1994	ISBN 011 752873 0
3rd report	1,3-Butadiene	December 1994	ISBN 011 753034 4
4th report	Carbon monoxide	December 1994	ISBN 011 753035 2
5th report	Sulphur dioxide	September 1995	ISBN 011 753135 9

The cover photograph is reproduced by
kind permission of Dr Peter Baxter.

Contents

A Recommendation for a United Kingdom Air Quality Standard for Particles

Expert Panel on Air Quality Standards

The Expert Panel on Air Quality Standards (EPAQS) was set up by the Secretary of State for the Environment in 1991 following the undertaking, in the Environment White Paper 'This Common Inheritance' published in September 1990, to establish an expert panel to advise the Government on air quality standards. The terms of reference of the Panel are:

'To advise, as required, on the establishment and application of air quality standards in the United Kingdom, for purposes of developing policy on air pollution control and increasing public knowledge and understanding of air quality, taking account of the best available evidence of the effects of air pollution on human health and the wider environment, and of the progressive development of the air quality monitoring network.'

This report is one in a series which deals with pollutants suggested to the Panel by the Department of the Environment. Reports will be made on individual pollutants except where the Panel decide to deal with more than one because of the relationships between pollutants.

MEMBERSHIP OF THE PANEL

Chairman

Professor A Seaton MD, FRCP, FRCPE, FFOM
University of Aberdeen Medical School

Members

Dr J G Ayres BSc, MD, FRCP
Birmingham Heartlands Hospital

Dr P J Baxter MD, MSc, FRCP, FFOM
University of Cambridge

Professor P G J Burney MA, MD, MRCP, FFPHM
United Medical and Dental Schools of Guy's and St Thomas's Hospitals, London

Professor R L Carter MA, DM, DSc, FRCPath, FFPM
Royal Marsden Hospital and University of Surrey

Mr J W Cherrie BSc, FIOH
University of Aberdeen and Institute of Occupational Medicine, Edinburgh

Dr A E Cockcroft MD, FRCP, DIH, FFOM
Occupational Health and Safety Unit, The Royal Free Hospital, London

Dr D N M Coggon MA, PhD, DM, FRCP, FFOM
MRC Environmental Epidemiology Unit, University of Southampton

Dr R G Derwent MA, PhD
Meteorological Office

Professor R M Harrison PhD, DSc, FRSC, FRMetS, FRSH
University of Birmingham

Professor S T Holgate MD, DSc, FRCP, FRCPE
Faculty of Medicine, Southampton General Hospital

Mr R E Waller BSc
Consultant, London

Observers

Dr S Bristow PhD (to 1995)
Dr T L Ogden PhD (from 1995)
Health and Safety Executive

Dr P T C Harrison PhD, CBiol, MIBiol
Institute for Environment and Health, Leicester

Mrs A L McDonald BSc, MSc
Department of Health

Secretariat

Dr M L Williams PhD
Department of the Environment

Dr S M Coster PhD
Department of the Environment

Dr R L Maynard BSc, MB, BCh, MRCPath, FIBiol
Department of Health

Dr J B Greig MA, DPhil
Department of Health

Ms C J Hartley BSc, PGDipLIS
Department of Health

ACKNOWLEDGEMENTS

We thank the following individuals and organisations for their help.

Mr Steve Moorcroft, TBV Science, Landsdowne Building, 2 Lansdowne Road, Croydon, Surrey CRO 2BX for the provision of air quality data.

AEA Technology, National Environmental Technology Centre, Culham, Abingdon, Oxfordshire OX14 3DB for their help with the analysis of United Kingdom air quality data.

Dr Sarah Walters and Miss Jo Wordley of the Department of Public Health, Medical School, University of Birmingham for carrying out, at the request of the Panel, a study of air pollution and hospital admissions in Birmingham.

Mr Fintan Hurley of the Institute of Occupational Medicine, Edinburgh for comments and advice.

Introduction

1. Prior to the late 1960s, domestic burning of coal in the United Kingdom's towns and cities was an important contributor to the dense winter fogs, known as smoke fogs or, colloquially, as smogs. A particularly severe four day episode in London in 1952 drew attention to the effects of such smogs on human health, it being estimated that, during and shortly after the episode, some 4000 excess deaths occurred in the Greater London area as a result of the pollution and associated weather conditions. The severity of this effect was such that legislation, the Clean Air Act 1956, was enacted to control the burning of smoky fuels in towns and cities. Thereafter the air in the cities of the United Kingdom improved and smogs became a thing of the past. For a long time it was believed that the problem of urban air pollution had been solved. However, two factors have combined to make it necessary to review this opinion. First, the increase in volume of traffic in our cities has drawn attention to a different and increasing source of pollution and, second, recent studies in other countries, particularly the United States, have shown that modern urban air pollution may still be causing effects on health, even at concentrations far lower than those recorded during the 1950s and 1960s.

2. The original studies of the effects of the London smogs identified two pollutants, sulphur dioxide and smoke particles, as the ones most likely to have been responsible for the excess number of deaths. It was not possible to separate their effects and British and European legislation subsequently has required both to be measured and their concentrations in the air controlled simultaneously. The two pollutants usually occurred at the same time, since both are produced by coal burning. However, more recently, as motor vehicles have become the major source of urban particulate pollution, oxides of nitrogen have become the main associated urban pollutants while sulphur dioxide has become less important. The effects of sulphur dioxide have been considered in a previous report and in this report we consider the effects of particles.

3. In each of its previous reports the Panel has considered the effects of a single, well-defined chemical substance. This report differs in that it considers a pollutant, characterised by its physical properties, which may be of different chemical constitution depending on its source, and which is always a complex mixture of chemicals. In fact, particles as measured in the air are defined by the method of measurement. Originally, they were measured in the United Kingdom by the "Black Smoke" method, whereby air was drawn through a filter paper

and the blackness of the stain measured. This method is still widely used and gives a good indication of the concentration of particles produced by coal burning. It is, however, somewhat less useful for quantifying the particles produced by motor traffic, or those produced by reactions between gases in the air. Increasingly particles are being measured by a method that determines the mass of that fraction which is considered most likely to be deposited in the lung. These particles are called PM_{10} (**P**articulate **M**atter less than **10** μm in diameter[1]).

4. In this report the Panel discuss the sources of PM_{10} and their chemical and physical properties, the method by which they are measured and monitored, and the concentrations currently found in the United Kingdom. We discuss the evidence associating increases in their concentration in the air with adverse effects on health, and conclude by recommending an Air Quality Standard for the United Kingdom intended to reduce the magnitude of such effects.

[1] 1 μm is one millionth of a metre. Diameter here, and later in this document, refers to aerodynamic diameter, which also takes account of such variables as shape and density of the particle. Thus, a flat, plate-like particle may have a smaller aerodynamic diameter and therefore remain suspended in the air longer than a spherical particle of the same apparent physical diameter.

The Physico-Chemical Composition of Airborne Particles

5. The ability of a particle to remain suspended in the air depends essentially on its size, shape and density. Large heavy particles fall rapidly, while fine light particles remain suspended for longer. The same properties determine where in the human respiratory tract a particle lands when inhaled, so small particles can penetrate further than can larger ones. In general, spherical particles below about 10 μm in diameter have the greatest likelihood of reaching the furthest parts of the lung, the air spaces or alveoli, where the delicate tissues involved in the exchange of oxygen and carbon dioxide, the essential processes of respiration, are to be found. Particles larger than this, up to about 20 μm, may be deposited in the nose, throat and airways of the lung. Not all particles that are inhaled are deposited in the lung. Almost all particles larger than 7 μm are deposited in the nose or throat, and only about 20-30% of particles between 1 and 7 μm are deposited in the lung's air spaces. However, up to 60% of very fine particles, below about 0.1 μm, are deposited in the air spaces.

6. Airborne particles may be measured in several different ways. The simplest is to suck high volumes of air through a filter and to weigh the mass that accumulates over a given period. This method measures total suspended particulate matter and includes airborne particles of all sizes. In the Black Smoke method, lower flow rates are used and the larger particles are not collected, the concentration of fine particles being estimated by measuring the blackness of the stain produced on the filter paper. In order better to reflect the hazard implicit in particulate matter reaching the lung's air spaces, other methods have been developed to measure only those particles below a certain size. That most commonly used for measuring air pollution relies on the use of a size-selective sampler which collects small particles preferentially, collecting 50% of 10 μm aerodynamic diameter particles, more than 95% of 5 μm particles, and less than 5% of 20 μm particles. The resultant mass of material is known as PM_{10}. Different inlets allow collection of particles of different size ranges, for example $PM_{2.5}$, which represents the collection of 50% of 2.5 μm diameter particles. In this report, we refer usually to particles measured as PM_{10}. They are thus defined solely by their physical characteristics, and no particular chemical composition is implied.

7. Particles in the air are conventionally described as occurring in three different size ranges, or modes. The smallest, below 0.2 μm in diameter, called the nucleation mode, is formed by condensation of hot vapours, as from incinerators

and vehicle exhausts, and by chemical conversion of gases to particles in the atmosphere, as by oxidation of sulphur dioxide to sulphuric acid particles. These very small particles have a relatively short existence, since they coagulate into larger particles; nevertheless they are often the most numerous ones when particles are counted rather than expressed as mass. Particles between 0.2 and 2 μm in diameter make up the accumulation mode, and comprise those that have grown from the nucleation mode by coagulation or condensation of vapours. They are the most long-lasting of atmospheric particles, not readily being removed by rain and remaining in the air for some 7 to 30 days. Larger particles, greater than 2 μm, belong to the coarse mode; they are formed mainly by mechanical attrition and therefore consist mostly of minerals derived from soil, sea spray and industrial processes. These particles, because of their size, remain suspended in the air for only short periods.

8. The chemical composition of atmospheric particles clearly depends upon the major sources. For example, by the coast, sea spray may mean that salt is the main component, while close to a main road vehicle exhausts will determine the composition. Such variations need to be borne in mind when considering the results of epidemiological studies from different countries. Those particles of greatest concern, since the largest numbers of people are exposed to them, are those occurring in towns and cities, and some general indication can be given of their chemical composition. About 40-50% of the mass of airborne particles in the United Kingdom is soluble in water, and contains mainly sulphate, nitrate, chloride and ammonium ions. The insoluble fraction consists mainly of carbon, together with a range of minerals derived from soil. Many other elements and compounds are found in trace amounts, depending on local sources, and some of these, such as lead, dioxins and polycyclic aromatic hydrocarbons, may be toxic in their own right. The composition of the airborne particles differs markedly depending on the size fraction examined. Studies carried out in Leeds in the 1980s (see *Figure 1*) showed that, at that time, the finer particles, below about 2.5 μm diameter, comprised about 50% carbonaceous material from combustion processes and 40% ammonium sulphate and nitrate, while the coarser fraction, above about 2.5 μm, comprised about 60% insoluble soil and wind-blown minerals and 15% carbonaceous material, the residue being mainly salts.

Sources of Airborne Particulate Matter

9. Particles in the air may arise from a wide variety of sources, either natural or man-made. Of the former, forest fires and volcanic eruptions provide dramatic examples, while sea spray and the erosion of soil and rocks by wind are important sources in many localities. Biological sources are ubiquitous, and particularly in rural areas considerable numbers of pollen grains, fungal spores and their fragments contribute to the total mass of airborne particles. Man-made airborne particles result mostly from combustion processes, from the working of soil and rock, from many other industrial processes and from the attrition of road surfaces by motor vehicles. These types of particles, together with those derived from natural combustion sources, may be classified as either *primary* or *secondary*: the former, such as carbon particles from combustion, mineral particles derived from stone abrasion and salt from the sea, are released directly into the air, while the latter are formed in the atmosphere by the chemical reaction of gases, first combining to form less volatile compounds which in turn condense into particles. It is important to recognise that these particles, whatever their source or composition, are all measured as PM_{10} if they fall within the appropriate size range, and that therefore the potential hazards of airborne particles may well be different in different places. For example, in country districts the components of PM_{10} more likely to cause adverse effects may be fragments of pollen grains and fungal spores, causing allergic symptoms; whereas in cities the main components are likely to be derived from vehicle emissions and have quite different effects, discussed further in the sections on measurement and health effects.

10. Airborne particles arising from human activities come from a wide range of sources. The largest single source in urban areas is road traffic, and within this category the largest component is that derived from diesel exhaust, followed by lead-rich particles derived from cars running on leaded fuel. Currently, the cleanest type of vehicle (in terms of particle emissions) in common use is the petrol car with a catalytic convertor running on unleaded fuel. Inventory estimates suggest that in 1990 in Greater London about 86%, by weight, of *primary* PM_{10} emissions were derived from vehicle exhaust, and a national inventory of emissions of primary PM_{10} for the year 1993 ascribed 24%, by weight, of these particles to this source (see *Table 1*). As with many other pollutants, the proportionate contribution of road traffic to pollution *in urban*

areas is significantly greater than in the total national inventory. These inventories are presented in more detail in the third report of the Quality of Urban Air Review Group.

11. *Secondary* particles are less easy to ascribe to their original sources. They comprise mainly ammonium sulphate and nitrate, originating from oxidation of sulphur and nitrogen oxides to acids which are then neutralised by atmospheric ammonia derived from agricultural sources. The chemical processes involved in the formation of these secondary particles are relatively slow and their persistence in the atmosphere is prolonged. Thus, while road traffic may be the main source of the original oxides of nitrogen, and coal and oil burning the main sources of sulphur oxides, the secondary particles are distributed more evenly throughout the air with less difference between urban and rural areas. They may also drift for considerable distances, and this results in transport of pollution across national boundaries. As an example, *Figure 2* illustrates the concentrations of particulate sulphate as measured at 88 sites across Europe in 1993, showing a marked east to west gradient and also a gradient across the United Kingdom, with higher concentrations being observed in the south and east.

12. The national emissions inventory shown in *Table 1* does not include secondary particles, or particles from natural sources, such as sea spray and wind blown dust. Analysis of data from particle samples collected in suburban Birmingham has given a useful indication of the sources of particles, although it should be noted that analysis was conducted on total suspended particulate matter (TSP) of a size range greater than PM_{10} which may give undue prominence to particles larger than PM_{10} from natural sources. The results, derived from two months of sampling, revealed six major source categories: airborne road dust and soil (comprising 32%) associated mainly with road surface dusts suspended by the movement of traffic, vehicle exhausts (25%), secondary particles (23%), coal combustion (11%), incineration and the metals industry (7%), and road salt plus marine aerosol (2%). Since these data were collected over a relatively short period in an area not wholly typical of UK cities and relate to TSP rather than PM_{10}, they should be viewed as indicative of source categories, rather than quantitatively defining the sources of particles in UK urban air. In wintertime pollution episodes in the major cities, the composition of PM_{10} is dominated by particles emitted from traffic and domestic coal burning. Throughout the year however the composition of the smaller $PM_{2.5}$ fraction, which may eventually prove to be of greater health significance, is dominated by vehicle exhaust emissions and secondary particles.

Table 1 Estimated United Kingdom emissions of PM_{10} by emission source, 1993, thousand tonnes per year

Source	Estimated Emissions*	Percentage of Total **
Power Stations (Fossil Fuelled)	40	15
Domestic	37	14
Commercial/public service	5	2
Refineries	7	3
Iron and Steel	20	8
Other Industrial Combustion	18	7
Construction	4	2
Industrial Processes	30	11
Mining and Quarrying	29	11
Extraction and distribution of Fossil Fuels	0	0
Solvent Use	0	0
Road Transport:		
Diesel	49	19
Petrol	13	5
Non-exhaust (Tyres and Brakes)	4	2
Other Transport	7	3
Waste Treatment and Disposal	0	0
Agriculture	1	0
Total	**263**	**100**

* Rounded to nearest thousand tonnes
** Rounded to nearest 1%

Measurement and Monitoring of Airborne Particles

13. Measurement of airborne particles in the United Kingdom has traditionally been by the Black Smoke method referred to above, and this continues to be the main method used for compliance with the European Community directive on Sulphur Dioxide and Suspended Particulates. In September 1995, Black Smoke was monitored in the United Kingdom at 255 sites, all of which have shown a marked downward trend in concentration over the years. As an illustration of this, measurements at sites in central London, Belfast, and Edinburgh between 1961 and 1994 are shown in *Figure 3*. However, with the changes in the main sources of urban pollution from coal burning to vehicle exhausts, Black Smoke is appropriate for measurement of soiling but is no longer regarded as the best method of measuring concentrations of airborne particles. PM_{10} (as defined in paragraph 6 above) is increasingly used as the standard measurement. PM_{10} is also currently regarded as the measurement best representing those particles most likely to penetrate into the lung and cause ill-health, although it is possible that advances in understanding may in the future indicate that another measure which excludes the larger particles (eg $PM_{2.5}$) may be more appropriate.

14. The Department of the Environment currently makes continuous measurements of PM_{10} in 16 cities in the United Kingdom (see *Figure 4*), using automatic apparatus that determines the mass of the particles of the selected size range. *Figure 5* shows the maximum daily average concentrations recorded for each month and site between 1992 and 1994. It can be seen that concentrations are highest in the winter months and lowest in the summer. However, the difference is less than that seen for other motor vehicle-derived pollutants such as carbon monoxide or oxides of nitrogen. This is because there is another important source of particles during the summer, the photochemical oxidation of sulphur dioxide and oxides of nitrogen to particulate sulphate and nitrate. *Table 2* shows the number of days in each month of 1993 when daily average PM_{10} concentrations exceeded 50 $\mu g/m^3$ (see footnote 2). The greatest number of exceedences occurred in Belfast (where coal is still a major fuel), London, Birmingham and Bristol, and the smallest in Edinburgh.

15. Since a high proportion of PM_{10} comprises fine particles that remain suspended for long periods, and since the stagnant weather conditions that give rise to winter pollution episodes often affect large areas of Britain, rises in

[2] 1 $\mu g/m^3$ is one millionth of a gram in every cubic metre of air. An adult breathes approximately 20 cubic metres of air in 24 hours.

particle concentrations often occur simultaneously in different parts of the country. Furthermore, such rises usually occur in association with rises in other traffic-related pollutants such as oxides of nitrogen. The daily average concentrations of PM_{10} monitored at six urban sites in the United Kingdom during November 1993, are illustrated in *Figure 6*, which shows the way in which such concentrations rise and fall more or less concurrently in widely separated cities.

Table 2 Number of days in each month during 1993 when the daily average concentration of PM_{10} exceeded 50 $\mu g/m^3$

Site	London Bloomsbury	Edinburgh	Cardiff	Belfast	Birmingham Centre
January	1	0	2	5	0
February	7	0	1	8	0
March	2	0	4	3	2
April	4	0	6	4	7
May	3	0	3	6	3
June	3	0	1	3	3
July	1	–	0	0	0
August	1	0	–	0	0
September	0	0	–	1	1
October	0	0	–	8	0
November	7	2	2	7	8
December	0	0	0	0	0

Site	Newcastle	Leeds	Bristol	Liverpool
January	0	1	0	–
February	1	4	2	–
March	1	5	2	–
April	2	0	4	2
May	0	0	3	1
June	2	1	1	–
July	0	0	0	0
August	–	1	0	0
September	–	1	1	1
October	0	1	0	0
November	6	9	12	13
December	0	0	0	0

Effects of Airborne Particles on Health

16. In contrast to the gaseous pollutants, with which it has often been possible to carry out controlled exposure of volunteers and of animals and thus reach reasonable conclusions about concentrations at which harm is likely to occur, no similar studies with mixtures of particulate pollutants characteristic of ambient PM_{10} have to date been technically possible. Thus, all the evidence which the Panel has considered has come from epidemiological studies of populations. Most have considered short-term effects on health and these have been of two types: first, analyses of health events, such as patterns of mortality or episodes of hospitalisation, relating these in time to episodes of air pollution, and, secondly, analyses over longer periods of the inter-relations between health events and routinely recorded concentrations of air pollutants. Several problems arise in such population studies. Most important is the weather, which is not only partly responsible for the occurrence of pollution episodes but is also strongly related itself to patterns of ill-health. In the United Kingdom, for example, cold weather in winter is associated both with urban pollution episodes and also with substantial increases in death rates and hospitalisations, making it very difficult to disentangle what are generally quite large effects of the weather (and sometimes associated viral epidemics) from the rather less striking effects of accompanying air pollution. A second important problem is the fact that air pollutant measurements have generally been made on an area and intermittent basis, and do not adequately represent the actual exposures of individuals in the population. Indeed, there may be a very wide range of individual exposures in people living in an urban area when the PM_{10} sampler shows just one value, some of these people being exposed to considerably higher concentrations. This one value is of necessity used in epidemiological studies to represent the exposures of individuals collectively. It is important to bear in mind that this technique, though perfectly acceptable scientifically, means that the true effect of low concentrations of PM_{10} on individuals cannot be determined with confidence from such studies.

17. The most usual objective of studies of the effects of particulate air pollution has been to investigate the possibility of associations between measurements of the pollutant and events such as death, changes in symptoms or lung function, episodes of hospitalisation, or doctor consultations, and to estimate the likelihood of any associations being due to chance. Such studies need to take account of other factors, such as weather, that may affect concentrations of air pollutants and that may also affect health. Individual epidemiological studies can

usually describe the strength of any associations between pollution and health; the likelihood of these being cause and effect depends also on such factors as the consistency of the findings across many studies and the demonstration of relationships between intensity of exposure and the effects. In addition, it is considered desirable (though not essential) that any association should be understandable in terms of known biological mechanisms before being accepted as causative.

18. The Panel have reviewed a large number of published studies investigating the association of particulate air pollution with excess mortality. The original London studies from the 1950s to the 1970s showed a relationship between rises in Black Smoke/sulphur dioxide and excess numbers of deaths from heart and lung diseases, although the absolute concentrations of pollutants then were very much greater than those occurring in the United Kingdom today. Subsequent studies in the United States have shown that these associations can still be demonstrated at the lower concentrations found in a number of cities in that country. An analysis of eight studies in different United States cities has calculated that a rise in PM_{10} of about 10 $\mu g/m^3$ (as a 24-hour average) may be associated with an increase in daily mortality of about 1%. Such an analysis of published studies has allowed an expert group of the World Health Organization to calculate the likely excess numbers of deaths associated with different concentrations of PM_{10}, and these are shown in *Table 3*. In four of the eight United States studies a breakdown of individual causes of death was given. Death from heart diseases, which was responsible for 45% of all deaths, showed an increase of 1.4% in relation to a rise of 10 $\mu g/m^3$, while death from lung diseases, which caused 5% of all deaths, rose by 3.4%. The strongest association was between death and average PM_{10} exposure over the preceding five days.

19. The Panel considered whether such excess death rates represented either more people dying overall, that is an increase in absolute mortality, or rather the deaths of already ill people being brought forward, perhaps by only a few days, and therefore fewer dying over the subsequent period. There is as yet little direct evidence on this, but the excess deaths are most clearly seen among older people, and are caused by acute worsening of conditions, such as coronary artery disease and chronic lung disease, that are most unlikely to have arisen as a direct result of a recent pollution episode. On the assumption that the demonstrated associations are indeed causative, we concluded on the basis of available evidence that PM_{10} pollution episodes are most likely to exert their effects on mortality by determining the time of death of those rendered susceptible by pre-existing disease. The Panel was not, however, able to dismiss the possibility that prolonged exposure to air pollution may contribute to the development of these diseases. One long-term study of six United States cities with contrasting levels of pollution has shown significantly higher mortality rates (overall and for diseases of the heart and lung combined) in the most polluted city. In addition, recent data from a large cohort in the United States give some support to the hypothesis that long-term exposure to particulate pollution in the past may have increased risks of lung cancer as well as showing an effect on mortality from heart and lung

diseases. We remain uncertain as to whether the confounding effects of social class have been adequately controlled for in these studies, but since the highest exposures to air pollution in cities commonly go hand-in-hand with other confounding factors such as cigarette smoking, poverty, poor housing, and unemployment, it is unlikely that any practicable study in the near future will produce more reliable results. Therefore, we conclude that long-term health effects remain a possible consequence of exposure to particulate pollution. In public health terms, however, any such effects of the levels of air pollution currently occurring in the United Kingdom are likely to be very small compared to those of the better-recognised social determinants of mortality mentioned above.

20. Since, as pointed out in paragraph 10 above, diesel exhaust is an important contributor to PM_{10} in urban areas, the Panel have considered the evidence associating lung cancer with exposure to diesel exhaust. Studies in two different strains of rat have shown that sustained, long-term exposure to high concentrations of inhaled diesel engine exhaust is associated with an increased incidence of benign and malignant lung tumours, the increase related to the exposure concentrations. Epidemiological studies have suggested an increased risk among heavily exposed workers, although this has not been a consistent finding in all investigations. The International Agency for Research on Cancer has classified diesel engine exhaust as a probable human carcinogen, in that there is limited evidence of its carcinogenicity in humans and sufficient evidence of carcinogenicity in experimental animals. The Panel considers that extrapolation from the observations made in people with heavy industrial exposure indicates that any risk of lung cancer from the concentrations found in the streets of the United Kingdom is likely to be exceedingly small. We have therefore given greater weight to other health effects when discussing the basis of an Air Quality Standard.

21. It has been suggested that the demonstrated relationships between particulate air pollution and deaths are unlikely to represent cause and effect, since it is not plausible that such low concentrations of particles could cause people to die of heart and lung disease and stroke. However, the relationships are remarkably consistent between different studies, and results similar to those in the United States and the United Kingdom have recently been found in cities of other countries such as Greece, Germany and China. There is also evidence of a relationship between the magnitude of the effect and the concentration of particles to which the population has been exposed. Such statistical associations increase the likelihood that the relationship is casual. It should be remembered, as mentioned in paragraph 16 above, that within a population exposed to particles measured at a fixed point, there will be some individuals who are exposed to either lower or much higher concentrations than those recorded centrally. Thus, not only will there be a range of susceptibility in the population but also there will be a range of exposures, and it is likely that some of those who are the most susceptible will be exposed to relatively high concentrations (compared with those monitored centrally) during any pollution episode.

Furthermore, the Panel consider it plausible that inhalation of particles of the physico-chemical types characteristic of urban air pollution episodes at appropriate concentrations could cause lung inflammation and this in turn could precipitate episodes of cardiovascular and pulmonary illness in susceptible individuals. We have therefore taken the view that episodes of particulate air pollution are responsible for *causing* excess deaths among those with pre-existing lung and heart disease.

22. Associations between ambient concentrations of particles and other indices of ill-health have also been reported. Again, the confounding effects of weather need to be taken into account, but there is consistent evidence that rises in concentrations of PM_{10} may be associated with increased numbers of admissions to hospital, increases in reported symptoms, and decreases in lung function. While not all studies have shown identical results, the coherence of the overall pattern is consistent with the hypothesis that particulate pollution is able to cause temporary worsening of already existing lung disease. The Panel believe that these results are also plausible evidence of a causative relationship, and consistent with the findings discussed above. This has been examined in detail by the Department of Health's Committee on the Medical Effects of Air Pollutants, whose conclusions have been made available to us. The expert group of the World Health Organization also estimated the approximate effects of different concentrations of PM_{10} on some indices of ill-health (see *Table 3*).

23. There has been a well-documented rise in the prevalence[3] of such allergic disorders as asthma, hay fever and eczema in the United Kingdom and other countries with a western lifestyle. This topic also has been examined in detail by the Department of Health's Committee on the Medical Effects of Air Pollutants, whose conclusions have been made available to us. The Panel have considered the possibility that outdoor air pollution, including particles, might have been in part responsible for this rise in allergic disease since, if so, such an effect would need to be considered in recommending an air quality guideline. We have concluded that there is no clear evidence that pollution at the concentrations found in the outside air is able to *cause* asthma (as opposed to provoking attacks in people who already have the disease) and we are of the view that outdoor air pollution is very unlikely to have contributed to the observed increase to any significant degree. It should be noted that this increase in allergic disease has occurred especially in young children over a period during which ambient concentrations of particles in the air of towns and cities in the United Kingdom have decreased.

[3] Prevalence means the proportion of people in a defined population at a given time or over a short period who have the disease in question. The proportion of young children with asthma and hay fever in Britain has approximately doubled over the last 20 years.

Table 3 Summary of short-term exposure-response relationship of PM_{10} with different health effect indicators

Health effect indicator	Estimated change in daily average PM_{10} concentration needed for a given effect (in $\mu g/m^3$)*
Daily mortality:	
5% change	50
10% change	100
20% change	200
Hospital admissions for respiratory conditions:	
5% change	25
10% change	50
20% change	100
Numbers of asthmatic patients using extra bronchodilators:	
5% change	7
10% change	14
20% change	29
Numbers of asthmatic patients noting exacerbation of symptoms:	
5% change	10
10% change	20
20% change	40

* Adapted, with permission, from WHO Regional Office for Europe, 1995. The original document indicates the published studies on which these estimates are based.

24. Since the pioneering work in London from the 1950s to the 1970s, relatively few investigations of the effects of particulate air pollution on populations have been carried out in the United Kingdom. The Panel have however reviewed two recent studies, in London and Birmingham. During an air pollution episode in London in December 1991, daily concentrations of Black Smoke rose to 228 $\mu g/m^3$ along with hourly nitrogen dioxide concentrations up to 423 ppb.[4] This episode was associated with an increase in overall mortality of about 10% and smaller increases in hospital admissions for lung disease and doctor consultations for upper respiratory symptoms, these adverse effects being confined to older adults. These findings are comparable with what might have been predicted on the basis of studies conducted on the effects of particles in the United States and elsewhere, but the relative contributions of the two pollutants remain unclear. The Panel commissioned a special study, in Birmingham, of hospital admissions over a 2-year period, from April 1992, in relation to measurements of

[4] 1 part per billion (ppb) is one part, by volume, in one thousand million, or 1 in 10^9; 1 ppb of nitrogen dioxide is equivalent to 1.88 $\mu g/m^3$ at 25°C and 1013 millibars.

PM_{10} in that city. The analysis took account also of temperature and concentrations of sulphur dioxide, nitrogen dioxide and ozone. Associations between PM_{10} and lung and stroke admissions were found, though the latter association was weak; no association was found with hospital admissions for heart disease. On the basis of these analyses, a rise in average daily PM_{10} of 10 $\mu g/m^3$ would be predicted to result in an increase of about one admission to hospital every other day for lung illness in Birmingham, a city of about 1 million people.

25. We have agreed that well-conducted studies have shown a relationship between concentrations of PM_{10} and health effects, such that the higher the concentration of particles, the greater the effect on the health of the population and, conversely, the lower the concentration, the smaller the effect. Such studies, however, have not been able to show whether there is a threshold concentration below which effects do not occur. The Panel considers that this may in part be a consequence of the fact, mentioned in paragraph 21, that measurements of particles made at a central monitoring site in such studies do not reliably reflect the exposures of all individuals in the area, which may have been higher or lower depending on their proximity to sources of pollution and their patterns of activity. Thus, where epidemiological studies have suggested an effect on health of very low concentrations of particles, this may be attributable to episodes of illness occurring in susceptible people who had in fact been exposed to higher concentrations. The concept of a threshold is particularly important; if a threshold does not exist there is no theoretical basis by which a standard can be fully justified in terms of improvement of health, since it could be argued that any figure chosen would have a smaller benefit than any lower figure, eventually down to zero. It is however arguable, since the risks to the population become smaller as the concentrations of PM_{10} fall, that there will come a point at which pollution would affect only a tiny minority of the population and further decreases in concentration would become ineffective in terms of public health benefits. We have therefore taken the view with respect to particles that there is likely to be a concentration at which adverse health effects are of only trivial public significance, even though that concentration is not at present known.

26. The Panel have noted that there is likely to be an irreducibly low concentration of particles in the air, due to natural processes. Indeed, even if all man-made particle generation ceased in the United Kingdom, because of the long-term persistence of the smallest particles this natural background concentration would be increased by drift from other countries, just as currently particles generated in this country will contribute to the world-wide concentration.

Justification of an Air Quality Standard for Particles

27. The Panel first considered the method by which any proposed standard should be measured. We concluded PM_{10}, rather than Black Smoke, to be the more appropriate method, since it represents most closely those particles of greatest potential toxicity and it has been used in many of the epidemiological studies on which our conclusions are based. We have also considered the time period over which PM_{10} should be measured and reported. The evidence indicates that acute health effects occur after pollution episodes lasting at least 24 hours. No studies have investigated episodes of shorter duration. In the absence of such studies we have therefore concluded that PM_{10} should be measured as a 24-hour running average.[5]

28. The Panel have concluded that the present evidence supports a causative link between exposure to particulate air pollution in the urban environment and certain indices of ill-health. In particular, we believe that public health benefits could accrue from further reduction in particle concentrations in our towns and cities, in terms of fewer episodes of doctor consultation and hospitalisation for respiratory and cardiovascular diseases. We are less sure of the benefits in terms of reduction in premature mortality, since if pollution-related deaths simply occur a few days early, the public health benefits are likely to be small, whereas if they occur years early they would be larger. On this important matter, as on the question as to whether current levels of air pollution actually contribute to the *causation* of heart and lung disease, we believe there is as yet insufficient evidence.

29. In recommending a concentration of PM_{10} at which a standard should be set, the Panel have differentiated between the concentration that in their judgement would be regarded as safe for individuals, including those with illness that makes them susceptible, and the concentration that would need to be achieved in order to produce significant benefit to the public health. Our task has first, therefore, been to decide on a concentration at which health effects on *individuals* are likely to be small and the very large majority of individuals will be unaffected. A rise from a daily average level of 20 to 50 $\mu g/m^3$, a concentration which was exceeded on average one day in ten in the Birmingham study

[5] Running 24-hour average PM_{10} concentrations are calculated by first calculating the hourly average PM_{10} concentrations over fixed periods from 00.00 to 00.59, 01.00 to 01.59, etc onwards. These hourly averages are then taken consecutively in groups of twenty-four and the 24-hour averages are calculated for 00.00-23.59, 01.00-00.59, etc onwards.

mentioned above, would be expected to be associated with just over 1 extra patient on average being admitted to hospital with respiratory disease daily in a population of 1 million. We have argued above that such admissions may represent the effects of exposure of susceptible people to concentrations at the upper extreme of the range represented by the figure recorded centrally. In terms of individuals, therefore, we have concluded that daily average concentration of 50 $\mu g/m^3$ (equivalent to the inhalation of not more than 1 mg in 24 hours) would be unlikely to affect the health of the very great majority of people. In the best judgement of the Panel, it is considered that very few individuals in the population will react adversely to this concentration of particles, to which all urban dwellers are exposed on a frequent basis.

30. In contrast, on a *population* basis, the Panel acknowledge that epidemiological studies have shown evidence of effects on health when local area measurements record concentrations of PM_{10} below 50 $\mu g/m^3$. If an Air Quality Standard set at 50 $\mu g/m^3$ were adhered to, as presently monitored, it is certain that some members of the local population would nevertheless be exposed to higher concentrations when living close to the major sources of the pollution, and it is likely that health consequences on a population scale would still be detectable. The Panel are of the view that the most effective means of ensuring a reduction in the adverse health effects of particulate pollution on the population is by a progressive lowering of the average concentrations of particles in our cities throughout the year, rather than simply by action aimed at limiting the number of peak concentrations exceeding 50 $\mu g/m^3$.

31. In the judgment of the Panel, 50 $\mu g/m^3$ is likely to be a safe concentration for exposure of the very large majority of *individuals*, and we recommend this figure as an ambient Air Quality Standard for PM_{10} in the United Kingdom, measured as a 24-hour running average. This figure is close to the 90th percentile of measurements of 24-hour averages made to date in the United Kingdom, that is one out of 10 measurements have exceeded it. It is between 20 to 30 $\mu g/m^3$ higher than the annual averages so far recorded, and has been exceeded regularly in winter in most cities in which it has been measured. In coming to this conclusion, the Panel are aware that we have had to make a number of judgements unguided by hard scientific evidence, and that we are recommending a Standard at which adverse effects on the health of *populations* may still be measurable. Since the greatest health benefits are likely to accrue from a reduction in the annual average concentrations of particles, we recommend that the Government implement a strategy which will reduce progressively both the numbers of 24-hour exceedences of 50 $\mu g/m^3$ and the annual average concentrations of PM_{10}. Such reductions could also be expected to ensure that there would be a decrease in peak concentrations.

32. Because of the many uncertainties surrounding the evidence upon which our recommendations are based, and since the Government has recently commissioned further research in this area, we believe that the recommended Air Quality Standard should be reviewed, in the light of United Kingdom experience and of any new data, within the next five years.

Recommendation for an Air Quality Standard for Particles

33. The Panel recommend an Air Quality Standard for PM_{10} in the United Kingdom of 50 $\mu g/m^3$ measured as a 24-hour running average. We also recommend that this Standard be reviewed after a period of, at most, five years in the light of any new data. We further recommend that the Government's programme of air pollution controls should aim to ensure that there is a decline in both peak and annual average concentrations of PM_{10}.

34. These recommendations taken together are intended to reduce the levels of exposure of the population to concentrations at which effects on health will become progressively less easy to detect and, eventually, unimportant in public health terms. It is intended that techniques for monitoring the 24-hour standard should be consistent with the PM_{10} measurements made by the Department of the Environment's Automatic Urban Network.

Figure 1 *Approximate composition of urban particles*

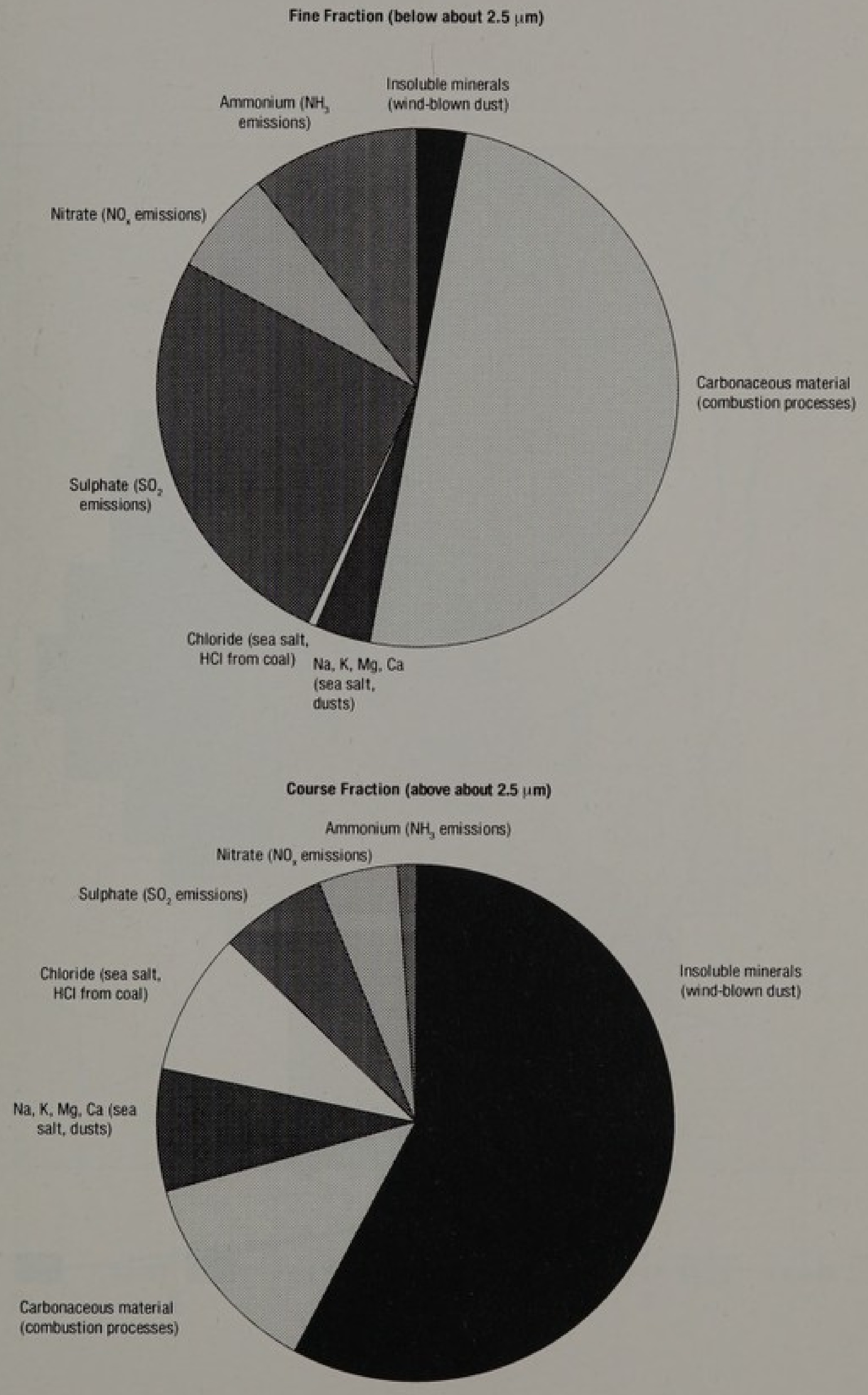


Figure 2 *Annual average concentration of particulate sulphate across Europe 1993 (μgS/m³)*

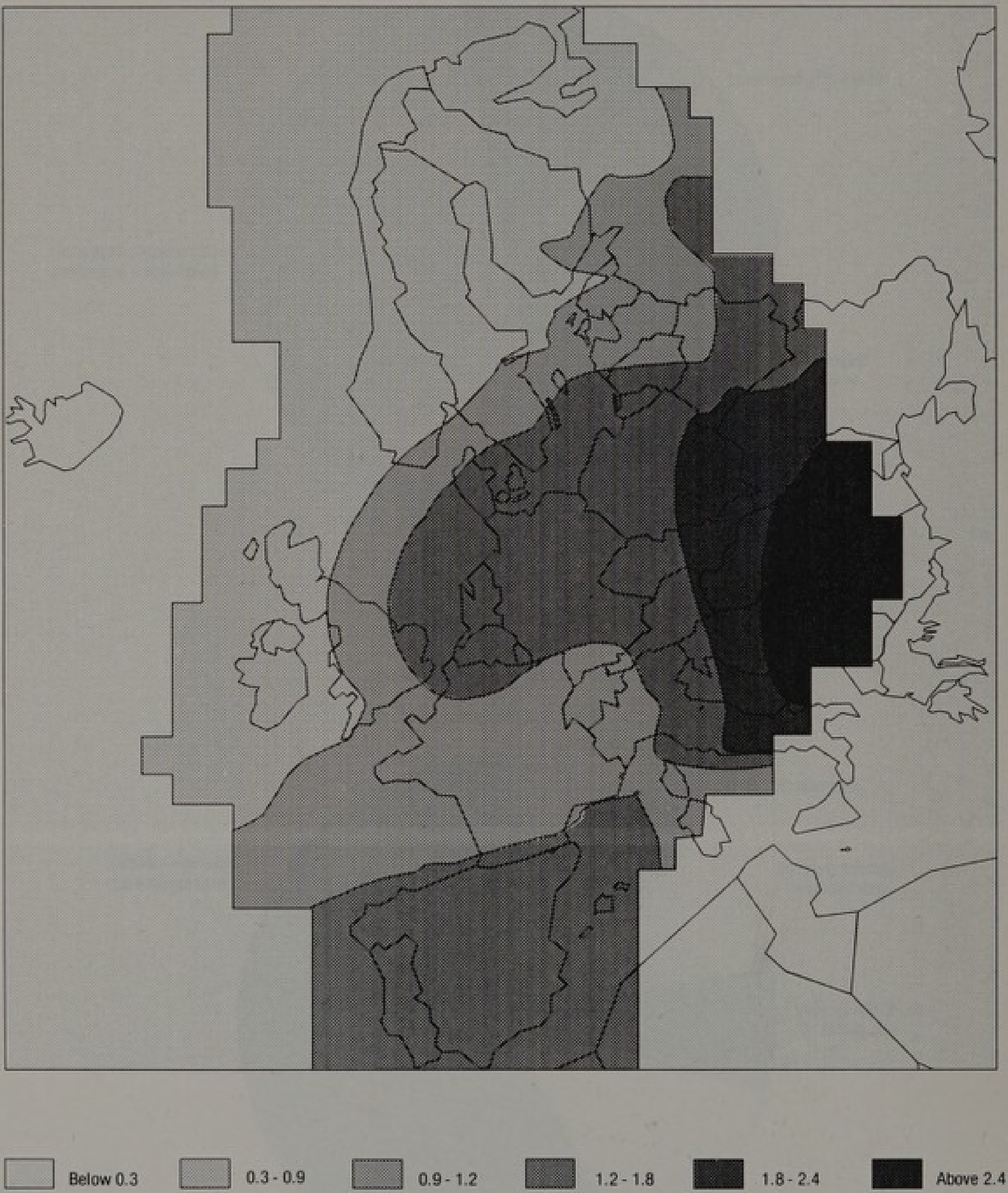


Figure 3 *Annual average concentrations of smoke ($\mu g/m^3$) at 3 urban sites between 1961 and 1994*

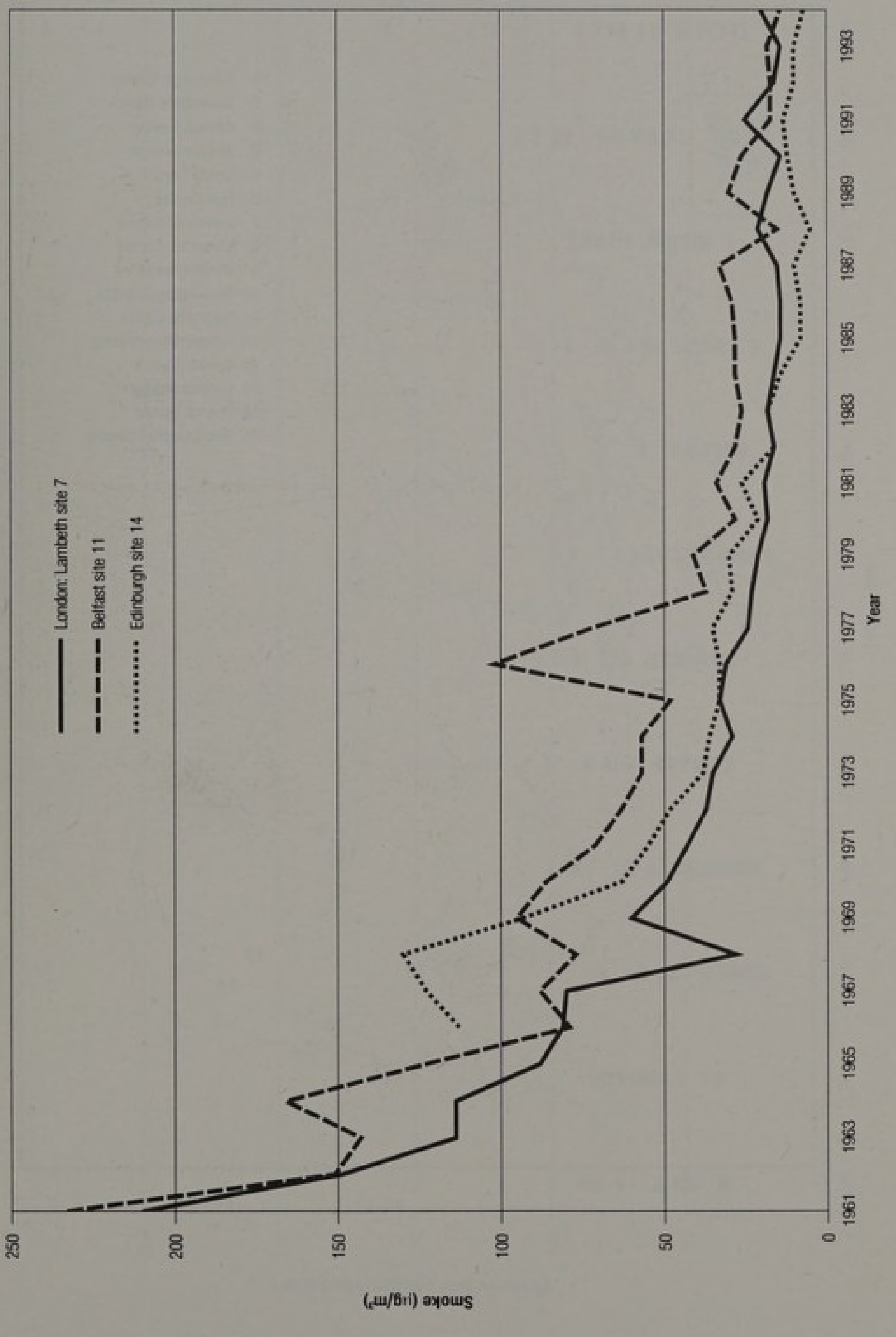


Figure 4 *Department of the Environment Automatic Monitoring sites for PM_{10} as at September 1995*

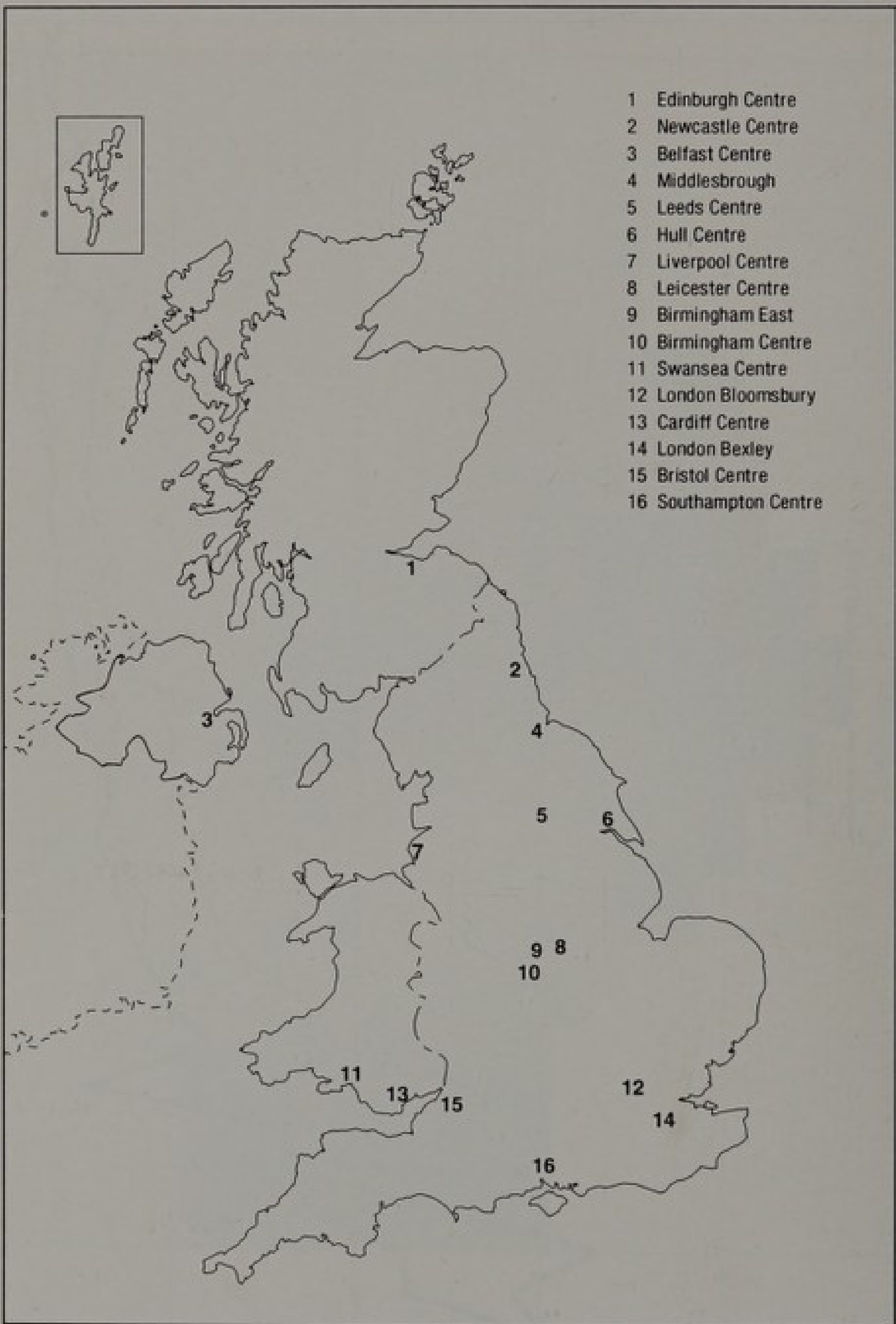


Figure 5 *The maximum daily average PM_{10} concentrations recorded for each month and site between 1992 and 1994 (Based on 385 values)*

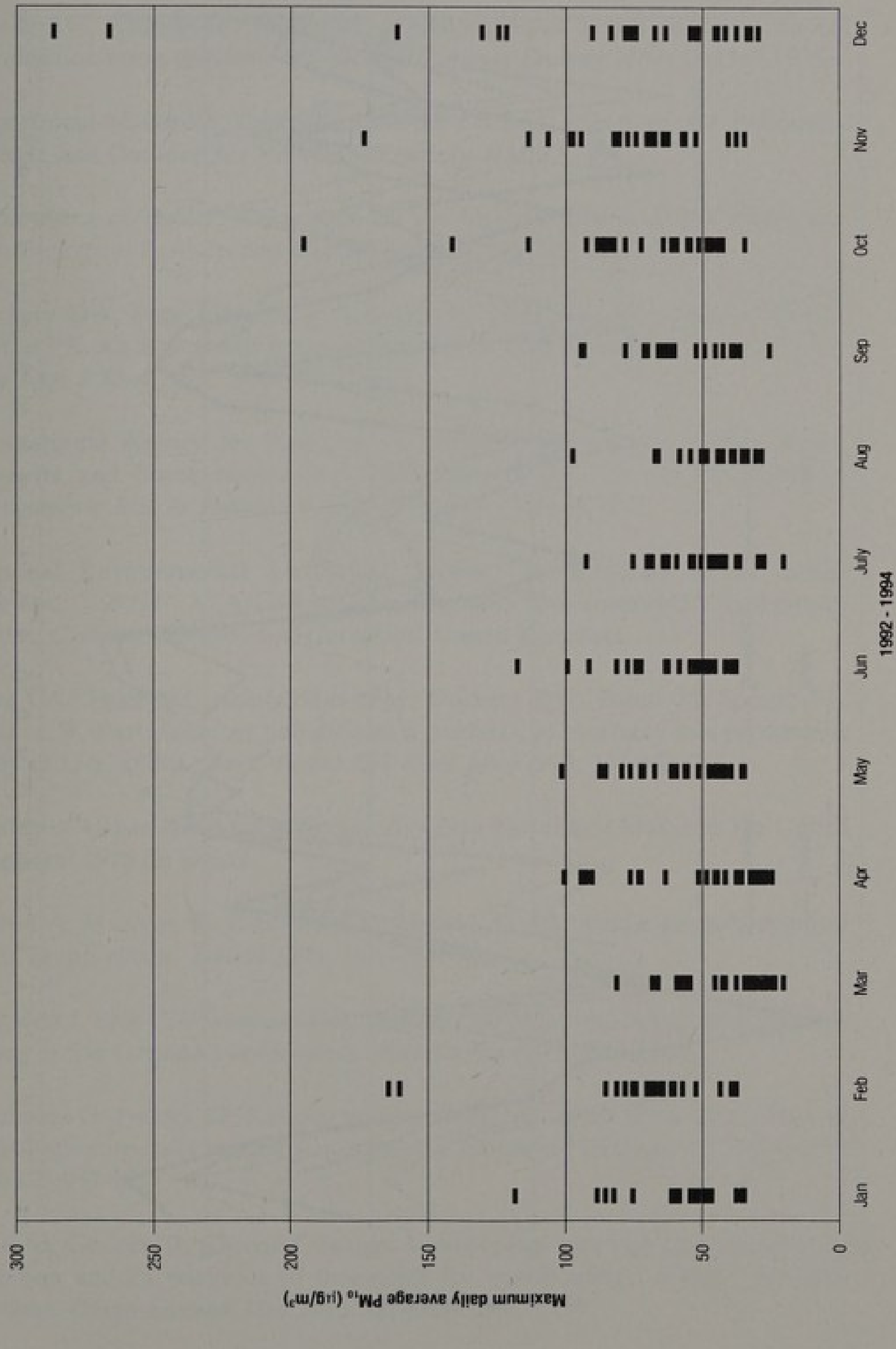
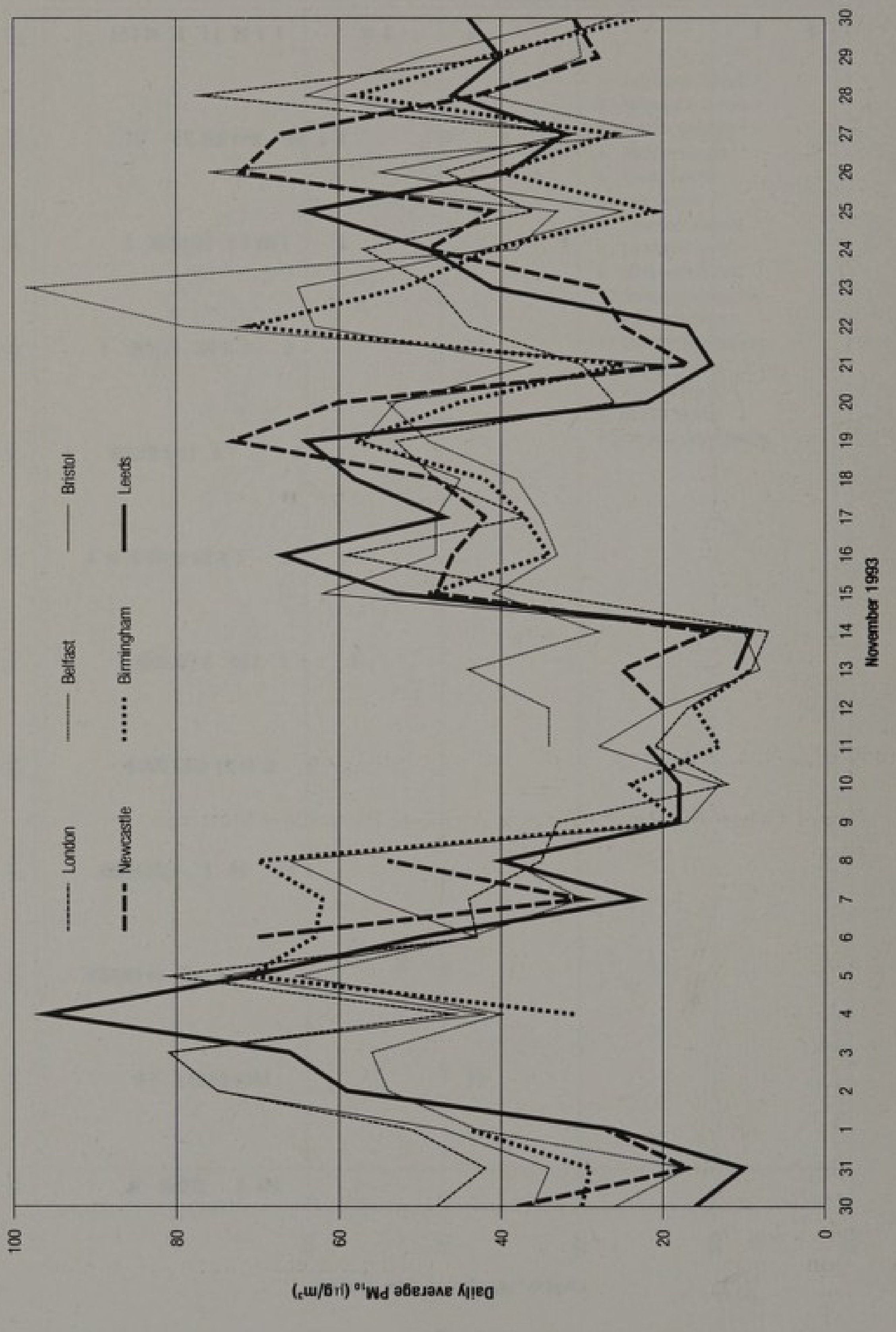


Figure 6 *Daily average concentrations of PM_{10} at six urban sites across the United Kingdom during November 1993*



BIBLIOGRAPHY

Anderson HR, Limb ES, Bland JM, Bower J, Ponce de Leon A, Strachan DP. Health effects of an episode of nitrogen dioxide air pollution in London, December 1991. *Thorax 1995*; 50:1188-1193.

Clarke AG, Willison MJ, Zeki EM. A comparison of urban and rural aerosol composition using dichotomous samplers. *Atmos Environ 1984*; 18:1767-1775.

Department of Health. Committee on the Medical Effects of Air Pollutants. Asthma and Outdoor Air Pollution. London: *HMSO 1995*.

Department of Health. Committee on the Medical Effects of Air Pollutants. Non-Biological Particles and Health. London: *HMSO 1995*.

Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG, Speizer FE. An association between air pollution and mortality in six U.S. cities. *New Engl J Med 1993*; 329:1753-1759.

International Agency for Research on Cancer. Diesel and Gasoline Engine Exhausts and Some Nitroarenes. *IARC Monographs on the Evaluation of Carcinogenic Risk in Humans 1989*; volume 46; IARC, Lyon.

National Environmental Technology Centre: *Air Pollution in the United Kingdom: 1993/4*. AEA/CSR1033/C. National Environmental Technology Centre, Culham, Abingdon, Oxfordshire, United Kingdom.

Pope CA, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE, Heath CW. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. *Am J Respir Crit Care Med 1995*; 151:669-674.

Quality of Urban Air Review Group. Airborne Particulate Matter in the United Kingdom. 1995 (in press).

Seaton A, MacNee W, Donaldson K, Godden D. Particulate air pollution and acute health effects. *Lancet 1995*; 345:176-178.

Schwartz J, Spix C, Wichmann HE, Malin E. Air pollution and acute respiratory illness in five German communities. *Environ Res 1991*; 56:1-14.

Touloumi G, Pocock SJ, Katsouyanni K, Trichopoulos D. Short-term effects of air pollution on daily mortality in Athens: a time-series analysis. *Int J Epidemiol 1994*; 23:957-967.

Watt M, Godden D, Cherrie J, Seaton A. Individual exposure to particulate air pollution and its relevance to thresholds for health effects: a study of traffic wardens. *Occup Environ Med 1995*; (in press).

World Health Organization, Regional Office for Europe. Update and revision of the Air Quality Guidelines for Europe. *Meeting of the Working Group "Classical" Air Pollutants, Bilthoven, Netherlands, 11-14 October 1994*. WHO: Copenhagen, 1995.

Xu X, Gao J, Dockery DW, Chen Y. Air pollution and daily mortality in residential areas of Beijing, China. *Arch Environ Health 1994*; 49:216-222.

Printed in the United Kingdom for HMSO
Dd 301604 C20 10/95 9385 3239

Expert Panel on Air Quality Standards: Particles

HMSO

HMSO

Pubished by HMSO and available from:

HMSO Publication Centre
(Mail, fax and telephone orders only)
PO Box 276, London, SW8 5DT
Telephone orders 0171 873 9090
General enquiries 0171 873 0011
(queuing system in operation for both numbers)
Fax orders 0171 873 8200

HMSO Bookshops
49 High Holborn, London, WC1V 6HB
(counter service only)
0171 873 0011 Fax 0171 831 1326
68-69 Bull Street, Birmingham, B4 6AD
0121 236 9696 Fax 0121 236 9699
33 Wine Street, Bristol, BS1 2BQ
0117 9264306 Fax 0117 9294515
9-21 Princess Street, Manchester, M60 8AS
0161 834 7201 Fax 0161 833 0634
16 Arthur Street, Belfast, BT1 4GD
01232 238451 Fax 01232 235401
71 Lothian Road, Edinburgh, EH3 9AZ
0131 228 4181 Fax 0131 229 2734
The HMSO Oriel Bookshop
The Friary, Cardiff, CF1 4AA
01222 395548 Fax 01222 384347

HMSO's Accredited Agents
(see Yellow Pages)

and through good booksellers

£6.75 net

ISBN 0-11-753199-5

9 780117 531991