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IMPACT ON HUMAN HEALTH OF AIR POLLUTION IN EUROPE



SCHERFIGSVEJ 8
DK-2100 COPENHAGEN Ø
DENMARK

TEL.: (45) 39 17 17 17
TELEFAX: (45) 31 18 11 20
TELEX: 15348

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EUR/HFA TARGET 21

This document presents the findings, conclusions and recommendations resulting from two working groups, one held in Research Triangle Park, NC, USA from 6 to 8 June 1990, and the other in Bilthoven, Netherlands from 9 to 12 July 1990. They were convened on behalf of the Regional Office for Europe to promote work aimed at achieving the following target in the health for all strategy.^a

TARGET 21

PROTECTION AGAINST AIR POLLUTION

By 1995, all people of the Region should be effectively protected against recognized health risks from air pollution.

Index terms

AIR QUALITY
AIR POLLUTION - adverse effects
ENVIRONMENTAL EXPOSURE
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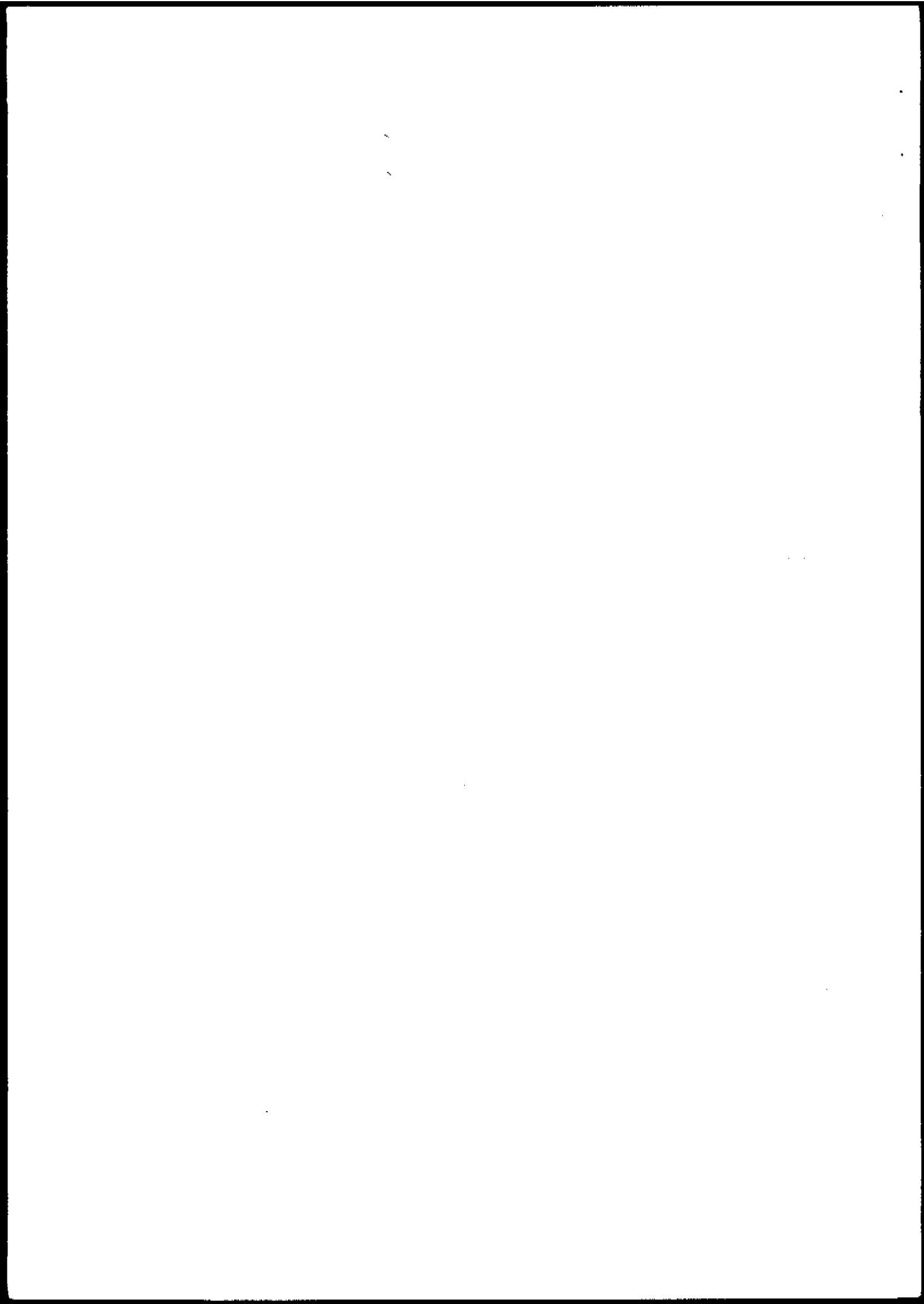
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^a *Targets for health for all*. Copenhagen, WHO Regional Office Europe, 1985 (European Health for All Series, No. 1).

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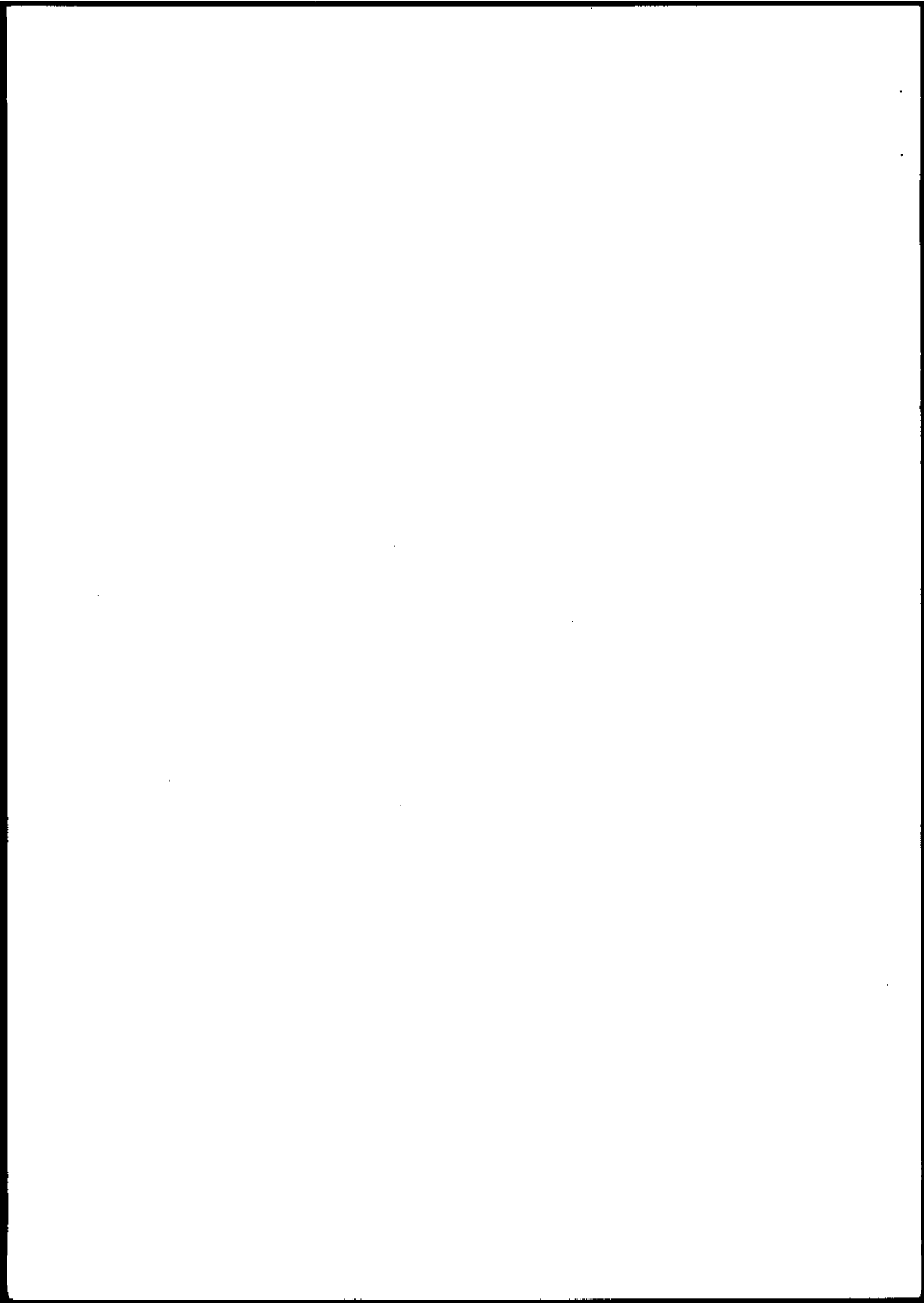
*IMPACT ON HUMAN HEALTH OF
AIR POLLUTION IN EUROPE*

Report prepared by the World Health Organization
Regional Office for Europe
Copenhagen, Denmark



CONTENTS

	Page
Preface	iii
1. Introduction	1
2. Air quality in Europe	2
2.1 Methodology	2
2.2 Available information	3
2.3 Air pollution levels in Europe	4
2.3.1 Summer-type episodes	4
2.3.2 Winter-type episodes	5
2.3.3 Long-term exposures in urban areas	7
2.3.4 Long-term multimedia exposure	8
3. Health effects	10
3.1 Summer-type episodes	10
3.2 Winter-type episodes	10
3.3 Long-term exposures in urban areas	11
3.4 Long-term multimedia exposure	12
4. Risk evaluations	14
4.1 Health impact of air pollution in populations	14
4.2 Health impacts of selected air pollution situations	14
5. Conclusions and recommendations	16
5.1 Conclusions	16
5.2 Recommendations	18
Figures	19
Annex 1. List of experts.....	26



PREFACE

This report is a first attempt to cover this very broad subject. It was prepared with the help of over twenty experts, following a request of and for the consideration by the United Nations Economic Commission for Europe (ECE) affiliated Executive Body for the Convention on Long-range Transboundary Air Pollution (EB) in Geneva, Switzerland.

Consequently, the WHO Regional Office for Europe (WHO/EURO) approached the Netherlands National Institute of Public Health (RIVM), which agreed in May 1990 to undertake the coordination of the work leading to the preparation of this report. More specifically, Dr Peter Rombout, Head of the Department of Inhalation Toxicology at RIVM, was assigned to plan and coordinate this project. This was done in coordination with the undersigned and the close cooperation of Dr Lester Grant and his staff from the Environmental Criteria and Assessment Office of the US Environmental Protection Agency (EPA) in Research Triangle Park, NC, USA.

Two working groups of experts were considered essential for achieving the expected results in the shortest possible period of time. The first met on the premises of the EPA in Research Triangle Park, NC, USA, from 6 to 8 June 1990, to discuss and evaluate effects on health from major air pollutants. The group included 13 experts from seven countries. Their first preliminary report was also reviewed, by correspondence, by three additional experts. It was then used as a basis for additional drafting, through which additional information was added on European air pollution situations, with special attention given to highly polluted conditions in countries of central and eastern Europe.

The second working group met on the premises of RIVM in Bilthoven, the Netherlands, from 9 to 12 July 1990, to discuss and evaluate data on the air pollution situation in Europe and merge the findings of both meetings into one final draft report. The second group consisted of 12 experts from four countries. A final drafting committee of five members continued to work on the report from 13 to 16 July, with the final version being provided to the ECE in Geneva on 17 July 1990. The list of experts involved in this study is given in Annex 1.

The report was issued by the ECE for the EB in its original English version on 30 July 1990 as a restricted document. This restriction has implied the following: "Documents prepared under the auspices or at the request of the Executive Body for the Convention on Long-range Transboundary Air Pollution are RESTRICTED for use by governments and organizations taking part in the work of the Executive Body, and should not be given to newspapers or periodicals, unless DE-RESTRICTED by the Executive Body."

The report, in its ECE edition, was sent to the official national bodies and/or focal points (entrusted by their governments to deal with the ECE) of all the European and North American ECE Member States, as well as to the secretariats of all the international governmental and non-governmental organizations, which are in official relation with the ECE with respect to the mentioned Convention. Moreover, every participant in the ECE/EB Working Group on Effects in Geneva, 27-29 August 1990, be it the representative from a Member State or from one of the organizations mentioned, could legally pick up a copy during the meeting, if present, and contribute to the discussion of the Working Group on this report.

At the end of the eighth session of the EB in Geneva on 23 November 1990, it was agreed to de-restrict the report. Consequently, it could be made available to WHO Member States, the health-related scientific and administrative community and to the general public.

Within the framework of the new European Centre for Environment and Health of WHO/EURO, it is intended to develop a more extensive study on the impact on human health of environmental pollution in Europe, including air pollution, to be entitled "Concern for Europe's Tomorrow". This study is expected to examine and evaluate a much broader data and information base, to be collected systematically from all the European Member States, and give the experts the possibility to prepare a more detailed and accurate assessment of the state of environmental and human health in Europe.

Dr Michael J. Suess
Regional Adviser for
Environmental Health Hazards

Copenhagen, January 1991

1. INTRODUCTION

This report is an initial attempt to provide an overall assessment of the impact of air pollution in Europe on human health. It also identifies immediately needed abatement and control measures and contains recommendations for more effective regional surveillance of human exposures and health impacts.

The report has been submitted by the WHO Regional Office for Europe at the request made by the Executive Body at its seventh session in November 1989. It was prepared during June-July 1990 by a task force of experts, coordinated by the National Institute of Public Health and Environmental Protection (RIVM), Bilthoven, the Netherlands, in cooperation with the Environmental Criteria and Assessment Office of the US Environmental Protection Agency (EPA), Research Triangle Park, NC, USA.

An array of investigations has shown that severe air pollution causes an increase in acute and chronic respiratory morbidity and in the severity of symptoms. Air pollution episodes in the past, such as in Donora, PA (1948) and London (1952), clearly demonstrated that air pollution can directly cause an increase in daily mortality. Comparable conditions still occur in certain European areas.

The quantitative assessment of the total impact of current levels of air pollution in Europe on human health is difficult because of the limited knowledge about concentrations, exposures and quantitative exposure-response relationships. Until recently, data on air quality were not publicly accessible for large parts of Europe, and only few data are now being systematically collected for the specific purpose of determining the adverse health impact on populations. Unfortunately, health risk assessment has still to be based on air quality data collected for other purposes and on insufficient knowledge of exposure-response relationships.

Most data presently available on air quality refer to outdoor situations. Yet, only relatively little time is spent by most people outdoors. Indoor concentrations may be higher or lower than those outdoors, and a complete human exposure assessment requires an evaluation of both outdoor and indoor concentrations. This report, being a first attempt, considers only outdoor concentrations, thus also hindering risk assessment.

Human exposure to air pollution concerns mixtures of different nature and sources. The only way exposure to these mixtures can be reduced is by eliminating the source, or at least reducing its strength. This will reduce, simultaneously, all primary and most of the secondary pollutants and depositions, as well as their direct and indirect effects on health, the ecosystem and materials.

The health risk assessment in this report is limited to four major air pollution situations:

- 1) summer-type episodes, which cause acute symptoms and health effects. The severity of this local, regional and/or mesoscale pollution situation can be characterized by the 1-h or 8-h average ozone (O_3) concentration;
- 2) winter-type episodes, which cause an acute increase of respiratory morbidity and mortality. The severity of this regional to mesoscale pollution situation can be characterized by the 24-h average concentration of sulfur dioxide (SO_2) and suspended particulate matter (SPM);

- 3) long-term exposure in urbanized areas to high levels of air pollution, which causes an array of acute and chronic health effects. The severity of this pollution situation may be characterized by the annual average concentrations of SO₂ and SPM; and
- 4) long-term multimedia exposure due to pollutants emitted into the air, such as heavy metal compounds, which causes systemic effects.

The next chapter discusses the geographical distribution of the levels of some air pollutants, which are indicators of the various air pollution situations. Chapter 3 reviews the health effects associated with major air pollution situations. Chapter 4 assesses the health impact from air pollution by relating indicator pollutant levels in the different situations to relevant exposure-response relationships and the Air Quality Guidelines for Europe, WHO Regional Office for Europe, Copenhagen, 1987.

The air quality guidelines (AQGs) (WHO/EURO, 1987) are formulated to ensure that populations which are exposed to concentrations lower than the guideline value will not suffer harmful effects. In cases where the guideline for a pollutant is exceeded, the probability of harmful effects will increase.

The report also considers new research findings published since the AQGs were issued. The last chapter presents conclusions and recommendations, including a particular recommendation on the immediate need for risk reduction.

2. AIR QUALITY IN EUROPE

In general, air pollution is caused by anthropogenic activities. The distribution of an air pollutant in the atmosphere is determined by the location of the source, its strength, meteorological conditions, atmospheric chemistry and deposition losses to soil and water surfaces. These factors contribute to high variations in the concentration of air pollutants in space and time. To assess the potential exposure of the European population to ambient air pollution, there is a need for air quality data covering Europe with a high spatial resolution related to demographic information and exposure-response relationships. The ambient air concentration data available at present are insufficient for making detailed concentration distributions for the whole of Europe.

2.1 Methodology

Existing mathematical dispersion models describe the behaviour and fate of atmospheric pollutants on a continental and regional scale and enable the calculation of pollutant levels on a local scale. If the results of validated models could be related to the population distribution, it would be possible to determine the distribution patterns of population exposure to air pollution levels associated with given or projected emission levels. Such an evaluation could then be made in terms of percentages of populations living in areas where the recommended AQG levels were exceeded.

An effective way of obtaining concentration distributions with a clear resolution is to combine continental and regional models. A European (continental) model calculates concentrations with a coarse spatial resolution, which can be regarded as background concentrations. Within the

framework of the Co-operative Programme for the Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe (EMEP), European concentration patterns of sulfur and nitrogen compounds have been calculated. In addition to climatological data, the model uses emission data on a scale of 150x150 km².

High-resolution emission data from unit areas (e.g., 5x5 km²) are required for calculating air pollutant concentrations by means of a model which covers an area of a regional scale (e.g., 300x300 km²). Background concentrations, calculated by the continental model, are required to take account of air pollutants introduced into the regional model from outside. Regional climatological and emission data bases with high spatial resolution are essential for using the regional model. Yet, emission data bases are presently available only in a few European countries.

The results of model calculations have to be validated by measured concentration values. If the agreement is satisfactory, these models could be used for assessing the potential population exposure to ambient air concentrations and predicting the effect of projected emission levels.

2.2 Available information

Concentration data bases

National monitoring networks are in operation in most of the European countries, but only a few of their stations report their data to international data collection programmes, such as the Background Air Pollution Monitoring Network (BAPMON, coordinated by UNEP/WMO), Global Environment Monitoring System (GEMS by UNEP/WHO), EMEP (by ECE), Oxidant Data (OXIDATE, by OECD), Tropospheric Ozone Research (TOR, by CEC/DG XII), and Community Data Bank on Air Quality (CODABQ, by CEC/DG XI). Fig. 1 presents the locations of GEMS, EMEP, and OXIDATE stations. An overview of concentration data bases on a continental scale is given in Table 1.

Table 1. International data bases of air pollution concentrations

Pollutant	Rural area					Urban area	
	BAPMON	CODABQ	EMEP	OXIDATE	TOR	CODABQ	GEMS
As, Hg	-	-	-	-	-	-	-
Cd, Pb	-	x	-	-	-	x	-
NO ₂	-	x	x	x	x	x	x
O ₃	-	x	x	x	x	x	-
SO ₂	-	x	x	-	-	x	x
SPM	x	x	x	-	-	x	x

The interpretation of the data collected by the various programmes is often difficult. It is known that the location of monitoring stations, especially in urban areas, is not clearly defined, and therefore not necessarily representative for exposure. Furthermore, a variety of measurement techniques exists, which may not be equally accurate. The quality control may also differ substantially. SPM is a notorious example when it comes to data comparison. In most of Europe, SPM is measured either by the smoke stain method or by a gravimetric method. With the smoke stain method fine respirable black material ("black smoke"), mainly originating from incomplete combustion, is sampled. Additional material, such as sulfates, nitrates, acidic aerosols and partially non-respirable fugitive dust are sampled when a gravimetric method is applied. In areas where coal smoke is the predominant source of SPM, the black smoke fraction may constitute a substantial (site specific) fraction of SPM as measured by a gravimetric method.

Emission data bases

Emission data bases on a European and sub-European scale are available for arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), oxides of nitrogen (NO_x), SO_2 , sulfate, and volatile organic compounds (VOCs). EMEP has an emission data base for a number of air pollutants covering Europe with a spatial resolution of $150 \times 150 \text{ km}^2$. However, the emission data for some of them are quite uncertain. Data bases on a national scale with a high spatial resolution are available only in a few West European countries.

Dispersion models

Several models exist that calculate air pollution concentration distributions over all of Europe. For example, EUROS and PHOXA (developed and used respectively by The Netherlands and jointly by the Federal Republic of Germany and the Netherlands) are models that describe the concentrations during winter- and summer-type episodes, respectively. Dispersion models on a regional scale, like the TREND-model in the Netherlands, are used at present only in a few North and West European countries.

2.3 Air pollution levels in Europe

2.3.1 Summer-type episodes

Episodes with increased photochemical activity occur during sunny and warm weather and low wind velocities. O_3 is formed from NO_x and VOCs under the influence of sunlight. Simultaneously, the concentrations of primary emitted compounds are increased, as are other non- O_3 secondary compounds (including gases, such as aldehydes and nitric acid; and aerosols, such as sulfates, sulfuric acid and nitrates). O_3 is considered to be the most indicative compound for determining the severity of an episode. Since the beginning of this century, O_3 production by photochemical processes has increased due to the tremendous growth of man-made activities. O_3 concentrations in remote areas are found to gradually increase, and a trend of 1% per year is reported for some locations.

Ground-level O_3 concentrations are affected world-wide by sources emitting nitrogen- and hydrocarbon-type compounds. Under specific meteorological conditions, when air mixing is limited and ultraviolet

radiation is intense, high O₃ concentrations can build up due to regional source emissions. The occurrence of such regional episodes is strongly related to the weather patterns, causing significant variations in the maximum observed 1-h O₃ concentration from year to year. At locations where topographical conditions trap the air, increases in O₃ concentrations may be determined predominantly by local sources and meteorological conditions.

Air quality data for O₃

At present, O₃ concentration data from monitoring stations are obtainable mainly from the north-western European countries. Iso-lines of 98-percentile of 1-h O₃ concentrations, based on data from the OXIDATE stations for 1986 (Fig. 2), are given as an example of the geographical O₃ distribution during a year without particularly severe episodes. The maximum values of the 1-h average O₃ concentrations during 1986 ranged from a low value of 120 µg/m³ in northern Scandinavia to a high value of 220 µg/m³ in densely populated areas in western Europe. In years with severe episodes, such as 1982 and 1989, 1-h O₃ concentrations of 300-350 µg/m³ were regularly observed for several days in parts of western Europe (Fig. 2). The number of days per year during which the 1-h 150 µg/m³ level is exceeded varies greatly depending on location and weather. In years with moderate photochemical activity, such as 1985 and 1986, the number of days varied, between 1 and 44 and between 2 and 54, respectively. In a year with high photochemical activity, such as 1982, the number of days during which the 1-h average O₃ concentration exceeded 150 µg/m³ varied from 10 to 90.

Information on 8-h average O₃ concentrations is more limited. Data from the Dutch monitoring network show a high correlation between 1-h and 8-h O₃ concentrations: the 8-h maximum value is about 80-90% of the 1-h maximum value in rural areas.

In a number of southern European metropolitan areas, relatively high O₃ concentrations are observed for long periods during the summer as a result of topographical conditions, a high degree of insulation and high precursor emission rates. In Athens, for example, 1-h average O₃ concentrations above 300 µg/m³ are observed for many days, while a maximum of 500 µg/m³ has been reported.

2.3.2 Winter-type episodes

Winter-type episodes occur when a high pressure system above Europe persists during several days. A strong temperature inversion limits the mixing of air in the lower atmospheric layers near the earth surface with air in the higher atmospheric layers, thus causing an accumulation of air pollution in the lower layers. The high pressure system is often accompanied with cold weather, leading to increased energy demand for spatial heating and thus to increased emission of air pollutants. The deposition of SO₂ and other pollutants is reduced when the ground is covered with snow, thus contributing further to an elevated pollution level. During such episodes the 1-h and 24-h average concentrations of many pollutants may increase by about ten-fold.

The winter-type episode can be of a local, regional or mesoscale character. The respective air pollution mixtures contain, in addition to SO₂ and SPM, compounds such as carbon monoxide (CO), nitric acid (HNO₃), and nitrogen dioxide (NO₂). During such episodes, the SPM consists mainly (about

90%) of respirable aerosols with a diameter of less than 10 μm . Of these, some 50% consist of black smoke and the remainder of "white smoke" (mainly nitrates and sulfates). Part of the aerosols may occur as acidic particles about which no extensive data are yet available. The concentrations of oxidizing compounds, such as O_3 , are low. The 24-h SO_2 and SPM concentrations are used as indicator pollutants for winter-type episode situations, as they correlate well with the concentration levels of other air pollutants.

Air quality data for SO_2 and SPM

Recently, two severe winter-type episodes occurred in north-western Europe, with maximum 24-h SO_2 and SPM concentrations of 900 and 700 $\mu\text{g}/\text{m}^3$, respectively. In urban areas, the SPM concentrations may reach higher levels than those of SO_2 . The severity of the episodes in north-western Europe has since declined due to the reduction in SO_2 emissions, and are expected to decline even further in the near future.

Systematic collection of data on regional background concentrations of SO_2 and SPM for southern Europe during episodes is lacking. The few available data suggest that, in general the 98-percentile of 24-h SO_2 concentrations will stay below 100 $\mu\text{g}/\text{m}^3$. In a number of cities (i.e., Athens and Milan) maximum 24-h SO_2 and SPM concentrations of 400-500 $\mu\text{g}/\text{m}^3$ occur. Table 2. gives data for Milan, which show a clear downward trend for the early 1980s and a steady state thereafter.

Table 2. Maximum observed 98-percentile of 24-h SO_2 concentrations in Milan, 1978-1987

year	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
SO_2 concentration ($\mu\text{g}/\text{m}^3$)	1011	1173	984	856	945	673	495	513	416	417

Winter-type episodes are more severe and occur more frequently in eastern Europe. For example, the 24-h average SO_2 concentrations in north-western Europe during the episode of December 1989 did not exceed 250 $\mu\text{g}/\text{m}^3$, while at the same time 24-h SO_2 levels of 1100-2500 $\mu\text{g}/\text{m}^3$ were observed in 4 cities in the south of the German Democratic Republic (GDR). In some areas of eastern Europe, the SO_2 emission is so high that elevated concentrations occur virtually during the whole winter (Fig. 3). In the densely populated northern part of the Czech and Slovak Federal Republic (CSFR), the GDR and southern Poland (Fig. 4), one may expect, based on model calculations, 24-h 98-percentile SO_2 values to be above 500 $\mu\text{g}/\text{m}^3$ (Fig. 5). This expectation is based on an SO_2 emissions inventory of 1982. Measured 98-percentile values for the southern part of Poland in 1987 agreed well with those calculations and ranged between 100 and 1300 $\mu\text{g}/\text{m}^3$. Measurements in Bohemia and Moravia, CSFR, in 1987 show that the 98-percentile of 250 $\mu\text{g}/\text{m}^3$ was exceeded at 32 of 45 monitoring stations, the highest value being 600 $\mu\text{g}/\text{m}^3$.

SO₂ concentrations in the other East European countries are probably lower than mentioned above, although in Hungary and Yugoslavia very high concentrations have been reported. No consistent data were available for the USSR. However, based on the EMEP emission inventory, it is expected that high SO₂ concentrations may occur in the intensively industrialized and densely populated Donezk area.

In Poland, the highest SPM concentrations are observed in the south of the country, with 98-percentile values ranging between 250 and 2200 µg/m³. For the CSFR and the GDR, the SPM concentrations are similar to those in Poland.

2.3.3 Long-term exposures in urban areas to high levels of air pollution

The composition of air pollution mixtures in urban areas depends on local activities such as power plants, smelters, petrochemical industry, domestic heating, waste incineration and traffic. Among the wide array of pollutants of concern are benzene, CO, dioxins, NO₂, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), SO₂ and SPM. In the absence of better indicators, annual average concentrations of SO₂ and SPM are used as an indicator of this air pollution situation.

Air quality data for SO₂ and SPM

SO₂ emissions in north-western Europe show a downward trend for the period from the early 1970s to the mid 1980s. Many countries have set standards to control the amount of sulfur in fuel and employed technologies for its removal. Also, some countries employ other energy sources such as natural gas and nuclear energy. But since the mid 1980s, SO₂ emission levels in some of the countries have stabilized or even increased slightly as a result of economic growth.

Correspondingly, one can observe a downward trend in SO₂ in most countries. In Brussels for example, the reduction since 1970 was more than 60% (Fig. 6). Annual average SO₂ concentrations in rural and urban areas for virtually all of north-western Europe are now below 50 µg/m³.

The trend of SPM emissions for the last 15 years is downward and has been achieved mainly by using SPM removal technologies and shifting to other energy sources. The annual average black smoke concentrations, contrary to SPM, have generally come down to below 50 µg/m³, except for a number of urban areas. However, in recent years these concentrations have stabilized or even started to increase slightly due to intensified diesel traffic (Fig. 6).

The trend of SO₂ emissions in southern Europe has shown virtually no change in 1980-1986, except for Italy, which reported a decline of 30% during this period. The few data available indicate that in general background annual average SO₂ concentrations are below 50 µg/m³. In some cities, such as Milan, current values are 80-90 µg/m³ (Table 3).

Annual average SPM concentrations in many cities exceed 50 µg/m³. In Lisbon, for example, the average SPM concentration over the period 1983-1985 was 110 µg/m³. In Athens, annual average black smoke concentration over

this period was about $120 \mu\text{g}/\text{m}^3$. Annual average SPM concentrations in southern Europe (e.g. Milan) have also been rising during the past few years (Table 3).

Table 3. Annual average SO_2 and SPM concentrations in Milan, 1980-1987

year	1980	1981	1982	1983	1984	1985	1986	1987
SO_2 concentration ($\mu\text{g}/\text{m}^3$)	246	236	175	149	139	118	117	82
SPM concentration ($\mu\text{g}/\text{m}^3$)	139	143	132	131	128	168	180	161

SO_2 emissions per capita in the CSFR, GDR and Poland are the highest in Europe (excluding the USSR). As far as is known, the trend of SO_2 emissions was upward during the 1970s and has stabilized at a high level during the 1980s. The high SO_2 emissions are primarily caused by the use of poor-quality fossil fuel with a high sulfur content and the absence of abatement programmes. SO_2 concentration data were very difficult to obtain before 1989, and a combination of models has therefore been employed. The results have been validated by measurements, which have recently become available for a number of countries. The calculations have demonstrated that the populations in large urban areas of the CSFR, the GDR and Poland are exposed to annual average SO_2 concentrations of $200\text{--}300 \mu\text{g}/\text{m}^3$. Fig. 3 shows SO_2 concentrations in Weimar, GDR, during the period 1985-1988. Averaged over the half-year winter period, SO_2 concentrations rose up to $500 \mu\text{g}/\text{m}^3$.

Less is known about the other East European countries. Yet, based on emission inventories, annual average SO_2 concentrations there are probably lower than in the CSFR, the GDR and Poland, though concentrations may still be high. In Zagreb, the annual average SO_2 concentration has been reported to be $70\text{--}100 \mu\text{g}/\text{m}^3$.

Nor is there much information available on SPM and black smoke concentrations. However, because annual average SPM and black smoke concentrations generally correlate to a high degree with SO_2 concentrations, it can be assumed that the annual average SPM concentrations in large parts of eastern Europe are high. In the south of Poland, annual average SPM concentrations in 1987 ranged between 100 and $300 \mu\text{g}/\text{m}^3$, and in the CSFR between 40 and $140 \mu\text{g}/\text{m}^3$. In some other East European urban areas, annual average SPM concentrations above $100\text{--}150 \mu\text{g}/\text{m}^3$ have been reported.

2.3.4 Long-term multimedia exposure

Various point and area sources emit hazardous gases and aerosols into the atmosphere, which may be deposited in the vicinity of the source or be sometimes transported over long distances. This results in increased pollution concentrations in different media, i.e. air, soil, water and food.

Long-term multimedia exposure of populations to pollutants such as heavy metals, PAHs, PCBs and dioxins by inhalation, and through oral and dermal routes result in increased body burdens. This pollution situation will be exemplified by As, Cd, Hg, and Pb.

Arsenic

The total emission of As from man-made sources in 1982 is estimated to be 5000 t, of which about 75% was contributed by the non-ferrous metal industry and the rest was attributed to fossil fuel combustion, sintering in foundries, cement production and the manufacture and use of As-containing products. The USSR accounted for about 40% of total emissions, followed by Poland (12%), the Federal Republic of Germany (7%), Spain (5%) and Yugoslavia (5%).

The highest concentrations are found in the vicinity of smelters and power plants. In the region of Katowice, Poland, and northern Bohemia annual average concentrations have been reported to be $0.02 \mu\text{g}/\text{m}^3$, due to the combustion of low-grade brown coal with a high As content. In north-western Europe, typical annual levels of As are about $0.003 \mu\text{g}/\text{m}^3$.

Cadmium

Emissions of Cd come primarily from the non-ferrous metal industry. Other sources are fossil fuel combustion, iron and steel manufacturing and waste incineration. Poland, Spain and the USSR together contributed in 1982 about half of the 1100 t Cd emitted. Depositions of Cd occur all over Europe, but the highest ones are found in eastern Europe (Fig. 7). Typical annual average Cd concentrations are $0.001 \mu\text{g}/\text{m}^3$, while in the Katowice area they have reached $0.08 \mu\text{g}/\text{m}^3$.

Lead

The total annual Pb emission in 1982 amounted to 90 000 t. The USSR accounts for about a third and France, Italy and the United Kingdom for another third. The dominant source for Pb emission in 1982 was gasoline combustion. However, in recent years, Pb emission from gasoline use has decreased drastically (up to 70%) in a number of countries, mainly because of the increased use of low-leaded and unleaded gasoline. Other important Pb sources are non-ferrous metal production, iron and steel manufacturing, and fossil fuel combustion.

Airborne Pb concentrations in remote areas are estimated to be below $0.01 \mu\text{g}/\text{m}^3$, in open areas near the cities - about $0.2-0.5 \mu\text{g}/\text{m}^3$, in urban areas - $1.5-2.0 \mu\text{g}/\text{m}^3$, and in the vicinity of smelters - $5-10 \mu\text{g}/\text{m}^3$. Pb levels in urban areas in north-western Europe have decreased to about $0.25 \mu\text{g}/\text{m}^3$ as a result of reduced of Pb in gasoline.

Mercury

Emissions of Hg come from a variety of sources during coal combustion, mining, smelting, and waste incineration. The total amount emitted in 1982 is estimated at 300 t. Concentrations in air are generally low, but the atmosphere is an important source for Hg in water. The information available suggests that the annual background concentrations of Hg are below $0.002 \mu\text{g}/\text{m}^3$.

3. HEALTH EFFECTS

Several major classes of air pollutants have the potential to affect the health of local populations and to exert much wider regional-scale health impacts through long-range transboundary transport. These pollutants result either from primary emissions or atmospheric transformation. Pollutants of human health concern include O₃, SO₂ and SPM, and heavy metals. They are discussed below in connection with the four specific pollution situations. The pollutants are used as indicators for the severity of these pollution situations because data on other compounds of health significance are lacking.

3.1 Summer-type episodes

During summer-type episodes the concentrations of O₃, NO₂, aldehydes and other photochemical air pollutants increase. O₃ is the most important photochemical oxidant with respect to health effects. Therefore its level is indicative of the severity of exposure.

Acute O₃ exposure causes transient decrements in pulmonary function, as has consistently been demonstrated in over 75 clinical, field or epidemiological studies. Typical O₃ symptoms include cough, chest pain, and difficulty in breathing. Exposure to other photochemical oxidants can cause eye irritation. Effects of 1 to 3-h O₃ exposures are relatively well understood. The quantitative characterization of effects from prolonged (6 to 8-h) exposure, single and repeated exposure to episodes, as well as from chronic exposure to O₃ is a major current issue. Experimental data point to the occurrence of a pulmonary inflammatory response with potential fibrogenic activity, which may be associated with the onset of irreversible chronic effects, especially after repetitive exposures.

It has been demonstrated that effects from O₃ increase with physical exercise and prolonged exposures. Also, for unknown reasons, some people are more sensitive than others. Another risk factor is an existing lung disease which has already caused loss of respiratory reserves. Children are of special concern, because they spend much of their time outdoors in summer and their level of physical activity is relatively high.

The 1-h O₃ AQG level is 150-200 µg/m³ and the 8-h AQG level is 100-120 µg/m³. However, recent studies indicate that there is very little or no margin of protection at these levels.

3.2 Winter-type episodes

Winter-type episodes are characterized by high concentrations of the indicator pollutants SO₂ and SPM. These episodes occur during periods of thermal inversions and low wind velocities. Under special circumstances such conditions can also occur locally in the summer. The pollution mixture also includes acidic aerosols.

The effects on human health include acute pulmonary function decrements (sometimes persisting for several weeks) and other respiratory effects, increased morbidity and increased consumption of medical services, and increased mortality. Individuals with airway hyperreactivity, such as asthmatics, and those with cardiovascular diseases are at special risk. Table 4 presents a summary of health effects at the lowest observed levels of SO₂ and SPM.

Table 4. Lowest-observed-effect concentrations for 24-h exposure to SO₂, black smoke (BS) and total suspended particles (TSP)

Effect	SO ₂ (µg/m ³)	BS (µg/m ³)	TSP (µg/m ³)
Excess mortality	500	500	
Increased acute respiratory morbidity (adults)	250	250	
Decrements in lung function (children)			180

Since the publication of the AQGs in 1987, further corroboration has been obtained confirming the exposure-effect statements in Table 4. It should be pointed out that at levels between those causing decrements in lung function in children and those causing increased morbidity in adults, respiratory symptoms will increase in frequency and severity. The assessment given in Table 4 should be used with caution because the composition of the pollution in winter-type episodes may vary for different locations which, in turn, may change the lowest-observed-effect levels.

Recommended AQG SO₂ levels of 500 µg/m³ and 350 µg/m³ for averaging times of 10 min and 1 hour, respectively, should protect people from acute respiratory effects. Data from recent literature do not present new information which would change or modify these recommendations.

The proposed AQG values for combined exposure to SO₂ and SPM provide protection against respiratory effects of short-term exposure. 24-h SO₂ levels should not exceed 125 µg/m³ in combination with 125 µg/m³ black smoke or 120 µg/m³ SPM.

3.3 Long-term exposures in urban areas to high levels of air pollution

In areas with strong emission sources, the annual average concentrations of air pollutants are elevated. Exposure to this type of air pollution can result in adverse health effects which are aggravated by the short-term effects of higher levels during episodes.

Health effects described for these pollutants are aggravation of respiratory symptoms, accelerated and persistent decline of pulmonary function, carcinogenic effects, effects on the immune system, aggravation of symptoms in patients with angina pectoris, effects on the nervous system, effects on fetal development, and other effects.

Exposure to the existing air pollutant mixture may include synergistic effects that cannot be predicted in detail and are perhaps not attributable to a single component. In the absence of better indicators, long-term average concentrations of SO₂ and SPM are used to signify the pollution burden during this situation. For single air pollutants and health effects, specific groups at risk might be identifiable; but for the whole mixture of pollutants, the general population should be considered at risk.

For long-term effects of SO₂ and SPM, the recommended AQG value is 50 µg/m³ SO₂ in combination with 50 µg/m³ black smoke, expressed as an annual mean.

Regular exposure and exposure from episodes to acidic aerosols may contribute to the total effects found in these regions. At present, quantifications or even estimates of effects are impossible because little reliable information is available on acidic aerosol concentrations and relevant exposure-response relationships.

3.4 Long-term multimedia exposure

Toxic chemicals emitted into the atmosphere may deposit on crops and soil and enter the human body by inhalation and through food and drinking water. The highest depositions are downwind from point and area sources.

Examples of multimedia exposures are discussed for As, Cd, Hg and Pb. Their effective dose depends on solubility and absorption, which may differ considerably. Therefore, adequate exposure-response relationships cannot be based on pollutant concentrations but, preferably, have to rely on internal exposure parameters, such as levels of Pb in blood. As these parameters generally correlate much better with metal content in precipitated dust than with the air concentrations, air quality guidelines for these compounds should be based on concentration levels in air combined with deposition rates and internal exposure values. In this respect, the existing AQG values are of limited value and will not be used below.

Arsenic

Ambient air As occurs mainly as the inorganic trivalent form arsenic-trioxide (As₂O₃), which is a soluble substance and is absorbed to a high degree from the lungs. Absorbed inorganic As is methylated in the body and excreted by the kidneys, and has a short biological half-life. Other As compounds with a lower solubility may be retained and accumulated in the lungs.

Occupational exposure to high concentrations of As₂O₃ has caused lung cancer and emissions of As from smelters have been associated with lung cancer among people living in the vicinity of such smelters. The unit life time cancer risk has been estimated to be 4x10⁻³ for each µg/m³ of As in ambient air.

Intake through food is small, but some seafood may contain high concentrations of organic arsenicals, which are absorbed and excreted without toxicological consequences. In certain areas, the inorganic As content of well water can be high. Each µg/l of As in drinking water is estimated to produce a lifetime As-associated skin cancer risk of 5x10⁻⁵ for both men and women. Arsenic can also cause systemic effects, especially in the cardiovascular and nervous systems.

Cadmium

Cd has a long biological half-life of 10-30 years, resulting in a considerable accumulation in the kidneys and the liver. When Cd concentrations in the renal cortex reach approximately 200 mg/kg (wet weight), some tubular functions will be irreversibly impaired. Several percent of an exposed

population may reach critical kidney concentrations with long-term dietary intake levels of 100 µg/d. Cd in urine is an acceptable indicator of the body burden.

The lung is typically a target organ only in occupational exposures to airborne Cd. Present ambient air levels of Cd generally do not constitute a direct health threat through inhalation, as the main route of entry is by food. However, both the International Agency for Research on Cancer and the US EPA have concluded that sufficient evidence exists for Cd causing lung cancer in animals and possibly also in humans.

Because Cd does not easily pass the placenta, the newborn is virtually free from the metal. Since tobacco contains Cd, smokers can absorb as much Cd from inhaled smoke as from food. Therefore, smokers generally have body burdens about twice as high as nonsmokers.

Mercury

Emissions of airborne Hg contribute to the Hg burden of the environment. One factor of particular importance is the entry of Hg into bio-methylation pathways, resulting in the formation of highly neurotoxic methylmercury (MethHg). The route of population exposure to Hg of major concern is ingestion of fish which contains MethHg. MethHg is absorbed to 90-100%, has a biological half-life of about 70 d and is widely distributed in soft tissues, particularly in the central nervous system. An early symptom is paraesthesia, which has appeared in adults at body burdens of around 30 mg, corresponding to a long-term daily intake of 0.3 mg. At higher body burdens, symptoms such as ataxia, visual disturbances and deafness can appear. MethHg passes freely across the placenta. Signs of neurological impairment and mental disturbances have been seen in children born to women who had body burdens of about half of those causing neurological disturbances in adults. In pregnant women, hair levels of 20 mg/kg Hg (as MethHg) or less are associated with increased risk of intra-uterine MethHg neurotoxic effects.

The Hg concentration in blood is an indicator of internal exposure to both MethHg and inorganic Hg. The Hg content of hair is a good indicator of internal exposure to MethHg. In case of exposure to airborne (inorganic) Hg, in addition to (oral) MethHg exposure, the Hg concentration in hair reflects both internal and external exposure without reliable differentiation.

At present, available data are not sufficient for establishing an air quality guideline value or any other limit value for Hg to protect against primary and secondary exposure-related effects.

Lead

Health effects of Pb exposure form a continuum ranging from subtle biochemical effects to increasingly more severe and overt toxicity, observed with more marked and higher level exposures. Blood Pb levels of 100-150 µg/l in women during pregnancy have been associated with effects on the fetus, resulting in lower birth weight and impaired neurological development and physical growth. Blood Pb levels in children as low as 100-150 µg/l cause subclinical or subtle effects, including mental and physical retardation, impaired learning abilities and impacts on haemoglobin and vitamin D synthesis; some of these effects are of unknown clinical significance. High exposures resulting in blood Pb levels in the range of 800-1000 µg/l in young children are often the cause of brain damage that may progress to coma or death.

The health effects of concern in adults include effects on haemoglobin synthesis, neurologic and renal effects, effects on blood pressure, and effects on reproduction. The effect on blood pressure seems to be the most sensitive and critical. Groups at special risk are pregnant women, infants and small children.

4. RISK EVALUATIONS

4.1 Health impact of air pollution in populations

When populations are exposed to air pollutant levels above the AQG values, adverse health effects may occur. In any given population, a number of people will be especially sensitive to a given pollutant. Young children and the aged are likely to be more sensitive, as are people with pre-existing lung disease and/or cardiovascular disease. People who exercise or work outdoors will increase their inhaled dose and hence be at increased potential risk. Thus, in any population there exists a range of sensitivities and a range of reactions.

For certain air pollutants, the present AQG values leave little or no margin of protection. When the concentrations of these pollutants rise above those values, an increasing number of people will experience effects with increasing severity. Furthermore, a simple relationship does not exist between the level of exposure and the total health impact in a population. There are differences in acute and chronic effects of air pollutants in terms of the concentrations which produce such effects, and repeated acute effects are also likely to produce chronic illness. This is an additional complication in the quantitative prediction of health impact from various patterns of air pollution exposure. Other factors, such as the fraction of time spent indoors, also modify exposure.

One way in which the exposure of a population and the impact on public health can be expressed is to determine the percentage of people living in a region where the concentration of the indicator pollutant exceeds the AQG value. Another way to assess the severity of exposure in a certain location is to determine the fraction of time during which the AQG value is exceeded. Where feasible, surveillance of health care utilization may also provide valuable information on the public health impact of air pollution.

It is not possible in this report to assess the health impact of air pollution situations as outlined above, because information on air quality, exposure and health effects is not yet available in the required form. Currently available data do not permit a quantitative assessment of health impacts. However, the effects of high concentrations of indicator pollutants in actual locations can be described in partially quantitative terms through data on acute and chronic morbidity, as well as on mortality.

4.2 Health impact of selected air pollution situations

Summer-type episodes

The severity of summer-type episodes is indicated by 1-h or 8-h mean O₃ concentrations. The 8-h AQG value is exceeded 10-100 times per year in north-western Europe and probably also in eastern Europe, as well as in several urban areas in southern Europe. The 1-h peak O₃ concentrations in

these areas range between 240 and 500 $\mu\text{g}/\text{m}^3$ (Fig. 2). A 1-h value of 175 $\mu\text{g}/\text{m}^3$ will be exceeded by 1.5-2.5 times. An 8-h AQG value will presumably be exceeded by 2-4 times.

Individuals exercising outdoors in the afternoon for several hours on days with peak O_3 levels of 240-500 $\mu\text{g}/\text{m}^3$ will experience mild to moderate respiratory symptoms and lung function decrements of 5-25%, accompanied by a pulmonary inflammatory reaction. The majority of Europeans are frequently exposed to O_3 concentrations exceeding the AQG values. Since the AQG value incorporates little or no margin of protection, widespread acute effects on the respiratory tract may be caused. The frequent and repetitive nature of O_3 exposure might contribute to irreversible decline of lung function as well as to structural lung damage.

Winter-type episodes

The severity of winter-type episodes is indicated by the 24-h mean values of SO_2 and SPM. The AQG value for SO_2 in combination with SPM is often (5-10 times a year) exceeded in large areas of eastern Europe by 2-6 times (Fig. 5). In some cities in these areas, the 1-h AQG value for SO_2 of 350 $\mu\text{g}/\text{m}^3$ is exceeded by 10-12 times. Recent estimates indicate that, in 1988, more than 50% of the population of the GDR was exposed to levels in excess of the AQG value for SO_2 and SPM. Similar situations occur in densely populated regions in the CSFR and Poland (Fig. 5). In north-western Europe the AQG value for SO_2 and SPM is exceeded by 2-4 times during winter-type episodes once every 5-10 years. In the larger cities in southern Europe this AQG value is frequently exceeded by 2-3 times. The majority of the population in the heavily industrialized areas of eastern Europe is exposed to 24-h average concentrations of SO_2 and SPM which frequently exceed by several times the lowest-observed-effect levels (Table 4).

Consequently, large parts of the population are exposed to levels that cause substantial acute pulmonary function decrements and severe respiratory symptoms. The population in eastern Europe is repeatedly exposed, which may lead to persistent decline in lung function. Reports on morbidity and mortality caused by these very severe exposure conditions are not available. Yet, during winter-type episodes of comparable severity in London in 1952 and 1962, significant increases in morbidity and mortality were observed. Similar effects are likely to occur in these highly polluted areas.

Long-term exposures in urban areas to high levels of air pollution

The severity of long-term exposure to increased levels of air pollution is indicated by the annual average levels of SO_2 and SPM. Other air pollutants should also be considered in assessing the health impact from long-term exposure. However, lack of exposure data and an incomplete understanding of exposure-response relationships prevent the incorporation of their possible effects in an overall assessment of the health impact for this air pollution situation.

The annual mean AQG value for SO_2 in combination with the black smoke fraction of SPM is exceeded every year in large areas in eastern Europe by 2-4 times. An analysis of monitoring data from the GDR indicates that, in 1988, 75% of the population was exposed to annual average levels above the AQG level. In western Europe, however, the AQG value is no longer exceeded, whereas in some urban areas in southern Europe the AQG value is still exceeded by 1.5-2 times.

Long-term exposure in urban areas to levels of SO₂ and SPM which exceed the AQG value will produce various health impacts, including marked pulmonary function decrements and respiratory symptoms as well as severe increases in morbidity and mortality. Exposure to permanently raised levels of air pollution is likely to prevent people from recovering from superimposed episodic exposures. Thus, otherwise reversible effects may become less reversible or fully irreversible. In addition, the likelihood exists that the AQG values for a number of simultaneously occurring pollutants will be approached or even exceeded. This could lead to increased sensitivity to one or more of these pollutants and to synergistic effects.

Long-term multimedia exposure

Certain sources emit not only indicator pollutants, such as SO₂ and SPM, but also aerosols and gases, such as As, Cd, Hg and Pb, and organic compounds generated by incomplete combustion of fuels and waste (e.g., PAHs, PCBs and dioxins). These pollutants may accumulate in the body, giving rise to concern with respect to exposure over long periods. The health effects from such multimedia exposure may lead to an excess cancer risk (e.g., As and some PAHs), neurotoxic effects (Hg and Pb), nephrotoxic effects (Cd), immunotoxic effects (dioxins) and other health effects.

Assessment of the health impact due to long-term multimedia exposure can only be presented in a qualitative way. Accordingly, air quality and deposition data on As, Cd and Pb (Fig. 7) clearly indicate that populations in large areas in eastern Europe may be chronically exposed, directly and indirectly, to elevated levels. This may result in health effects. In other urban areas in Europe comparable, though less severe, long-term multimedia exposure occurs.

A qualitative health impact assessment for Pb is given as an example. Surveys in 1979 and 1981 showed that blood Pb levels in many countries within the European Community have been in a range where neurological effects are likely in susceptible groups. In regions with additional point sources and heavy traffic, a higher health risk due to higher internal exposure has to be assumed. Reduction of Pb in fuel in some countries has resulted in a decrease of Pb concentrations in air and food, accompanied by a significant decrease of Pb body burden, as ascertained by a decrease of Pb levels in blood. In other countries where Pb reduction in fuel has not yet occurred, these problems continue to exist and require further measures. This example indicates that knowledge of actual exposure and exposure-response relationships may result in a targeted and successful abatement strategy.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

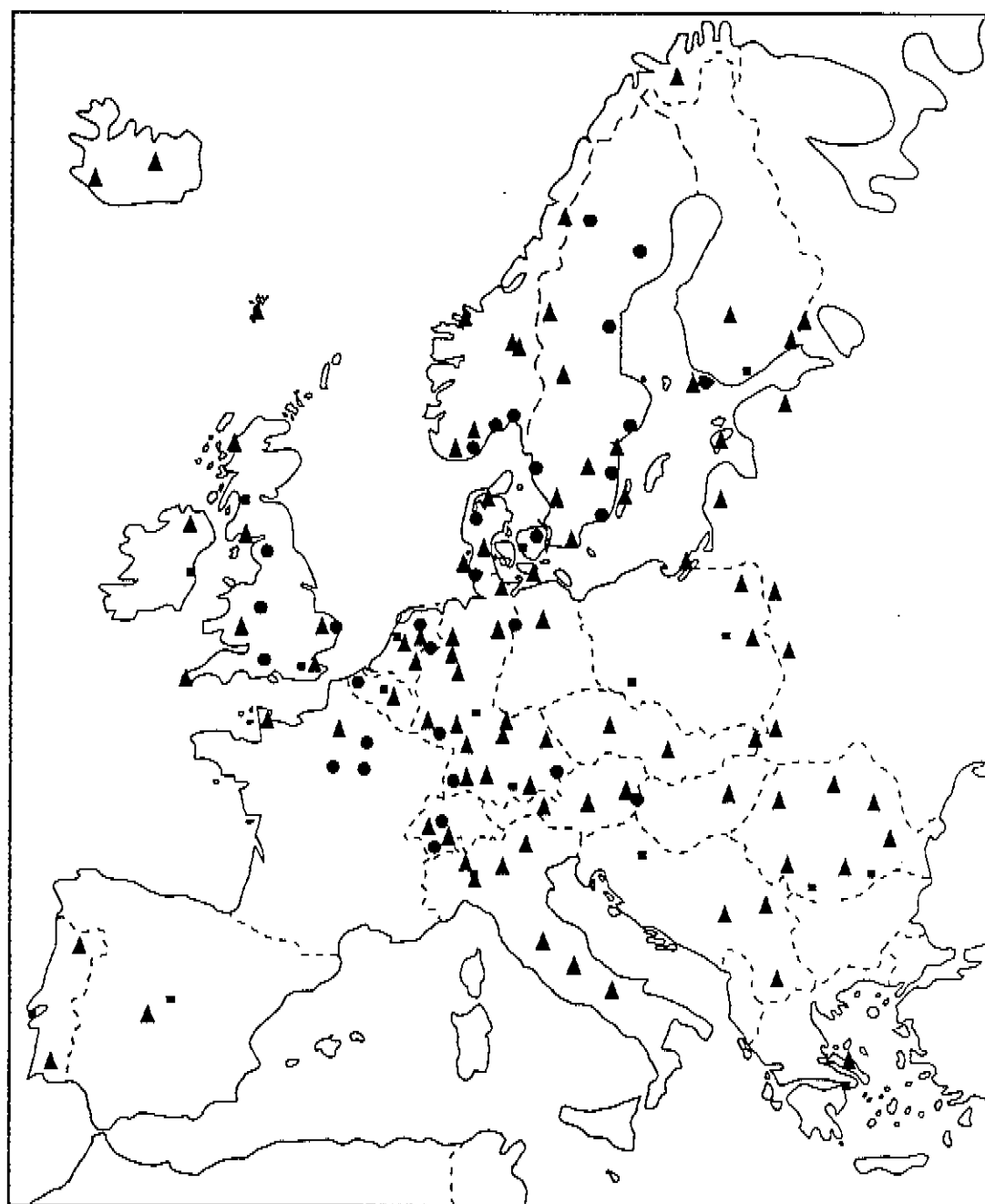
1. Millions of Europeans live in areas with air pollution severe enough to cause thousands of premature deaths each year and many more cases of chronic illness and disability. These effects are likely to be eliminated when regional and local air pollution levels are reduced to the WHO AQG levels. The improvements produced by air pollution abatement measures have been conclusively demonstrated in the London area and elsewhere in Europe.

2. Air pollutants occur in mixtures which are characteristic of certain situations. The four pollution situations considered in this report are: summer-type episodes (with photochemical oxidants being predominant), winter-type episodes (with SO₂ and SPM being dominant), long-term exposure in urban areas to high levels of air pollution, and long-term multimedia exposure. These situations require distinct and different abatement strategies.
3. Summer-type episodes: Geographically, summer-type episodes increase in frequency and severity from north-west to south-east Europe. The AQG values for 1-h and 8-h average levels of O₃, the indicator pollutant, are often greatly exceeded. Health effects consist of decreased lung function, eye, nose and throat irritation, cough, chest pain and inflammatory responses in the lungs. Repeated exposures may result in irreversible consequences such as chronic lung diseases. Abatement strategies include reduction of VOC and NO_x emissions.
4. Winter-type episodes: Meteorological and topographical conditions as well as source strength can interact to produce episodes lasting several days, during which SO₂ and SPM concentrations are elevated to far above the AQG 24-h average levels. Winter-type episodes can begin in areas as small as a town and spread to cover large areas of Europe. Where the use of high sulfur-content fuel and soft coal is predominant, these episodes will be more severe. Health effects may appear during or after episodes and consist of lung function decrements and increased respiratory symptoms, morbidity and mortality. On the basis of current exposures and observed mortality during earlier London episodes, present best estimates point to the likelihood of several thousand excess deaths per year due to winter-type episodes. Effective abatement strategies include fuel switching, flue gas treatment, increased energy efficiency and conservation.
5. Long-term exposures in urban areas to high levels of air pollution: Many urban areas contain a large number of strong air pollution sources and consequently produce annual average concentrations of SO₂, SPM and associated pollutants which exceed the relevant AQG annual average levels by 2-4 times. The health effects consist of increased respiratory symptoms, morbidity and mortality and increased cancer mortality associated with exposures to PAHs, benzene and possibly other carcinogens. Recent trends in SPM levels in western and southern Europe indicate increased concentrations, especially in cities. Abatement strategies include fuel switching, vehicle exhaust treatment and increased energy efficiency and conservation.
6. Long-term multimedia exposure: In a number of urban situations there are multiple sources of pollutants which emit heavy metal compounds and semi-volatile organic compounds that are deposited downwind from such sources. Single large point sources can also deposit substantial quantities of such compounds. Such deposits will accumulate in the soil over many years. Human exposure to these contaminants is mostly through the food chain and drinking water. Contaminated foods may also be ingested at locations remote from the source. Health effects from this type of exposure and abatement strategies depend on the specific pollutant.

5.2 Recommendations

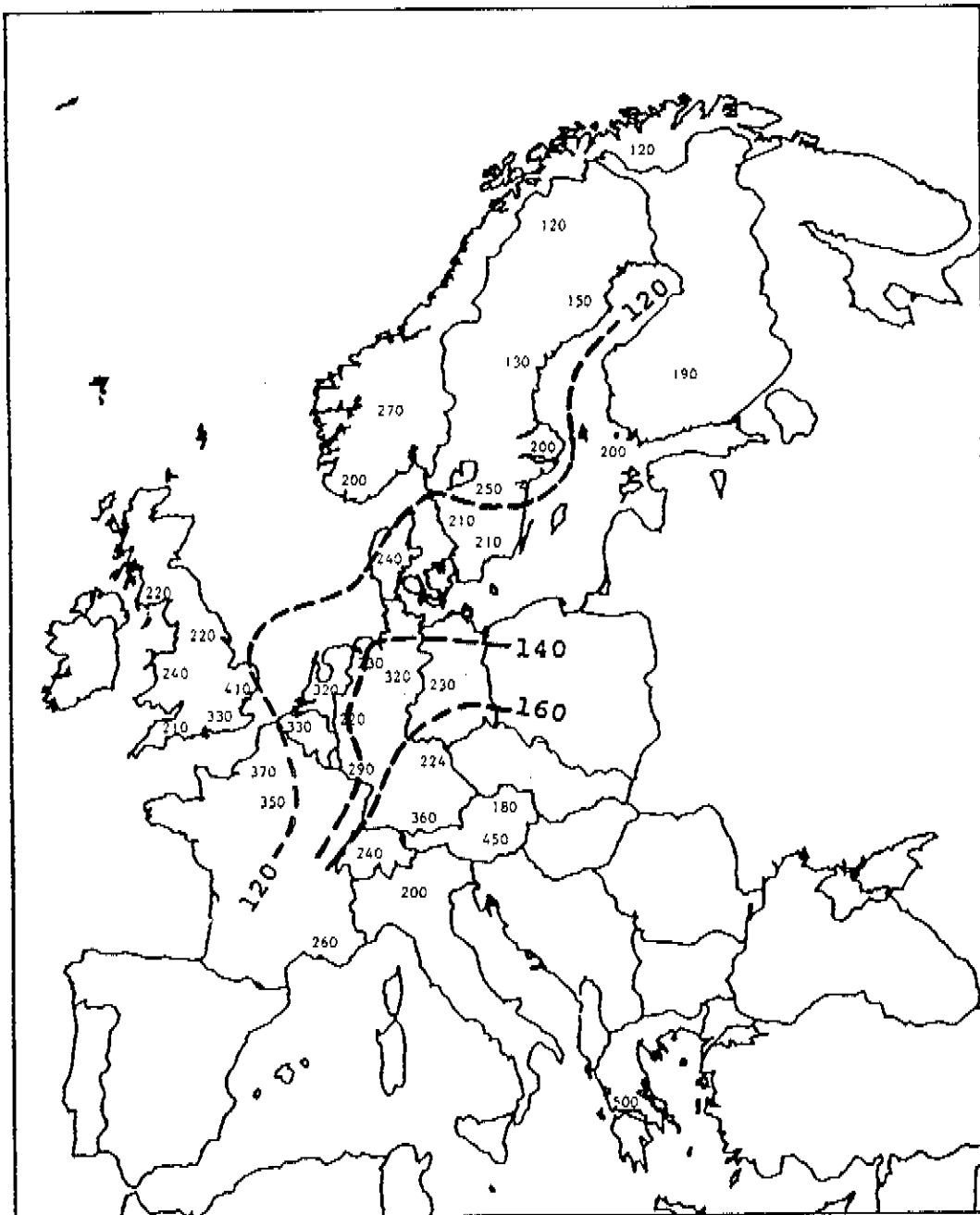
1. Immediate abatement and control action should be taken to reduce the severe impact of air pollution in Europe on human health. This action should not be delayed for additional studies.
2. Existing but unpublished data and internal reports on air pollution exposures and health effects should be reviewed and published as soon as possible.
3. Existing records of vital statistics and air pollution data should be made available for analysis and evaluation.
4. Appropriate and concerted strategies for monitoring of air pollution and measurement of health impact and abatement efficacy should be developed throughout Europe.
5. Effective health impact reduction strategies should be developed, based on the measurement and assessment of personal and population exposures and on quantitative exposure-response relationships.
6. Models of air pollution emission and dispersion should be expanded to include all of Europe and designed to facilitate population exposure assessment.
7. Comprehensive quantitative risk assessment should be made on the basis of actual human exposures, which are evaluated and compared with exposure-response relationships. Data on both these elements are scarce, and targeted research into these areas should be considerably expanded.

Fig. 1. Location of EMEP, GEMS and OXIDATE monitoring stations in Europe in 1985



- OXIDATE monitoring stations
- GEMS monitoring stations
- ▲ EMEP monitoring stations

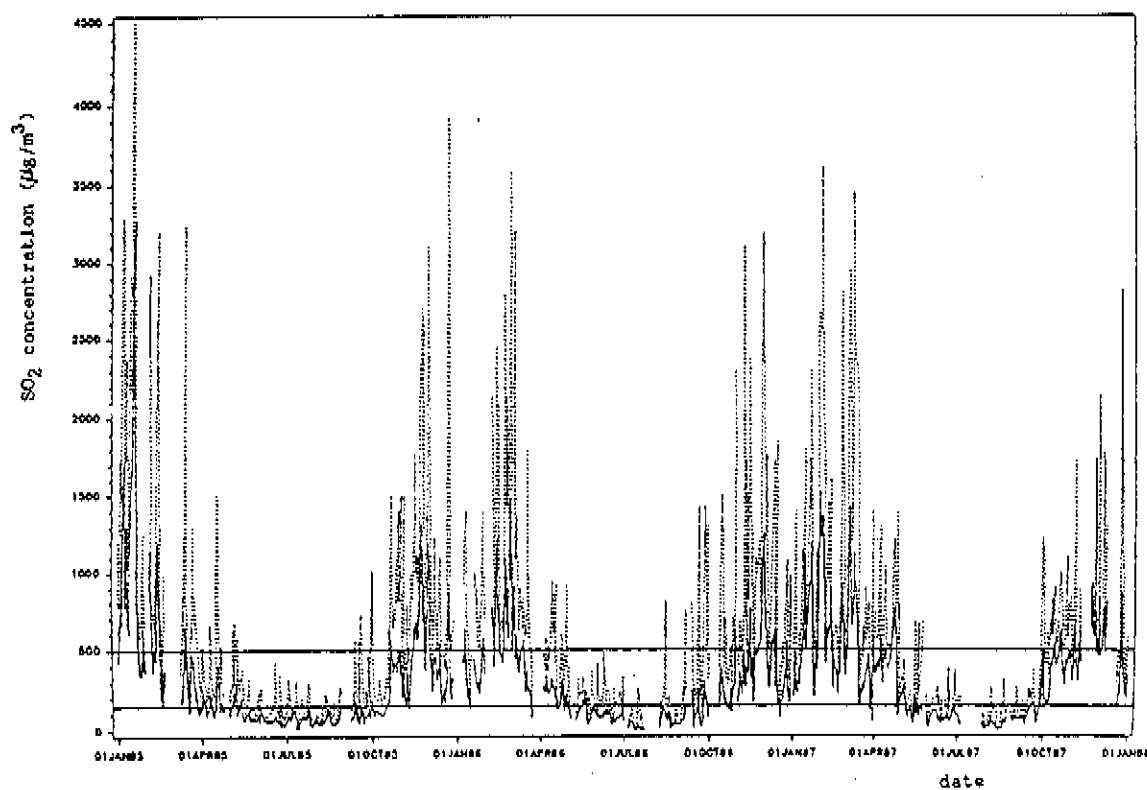
Fig. 2. Highest observed 1-h average O₃ concentrations in µg/m³, 1980-1989



Iso-lines: 98 percentile of 1-h O₃ concentrations,
April-September 1986

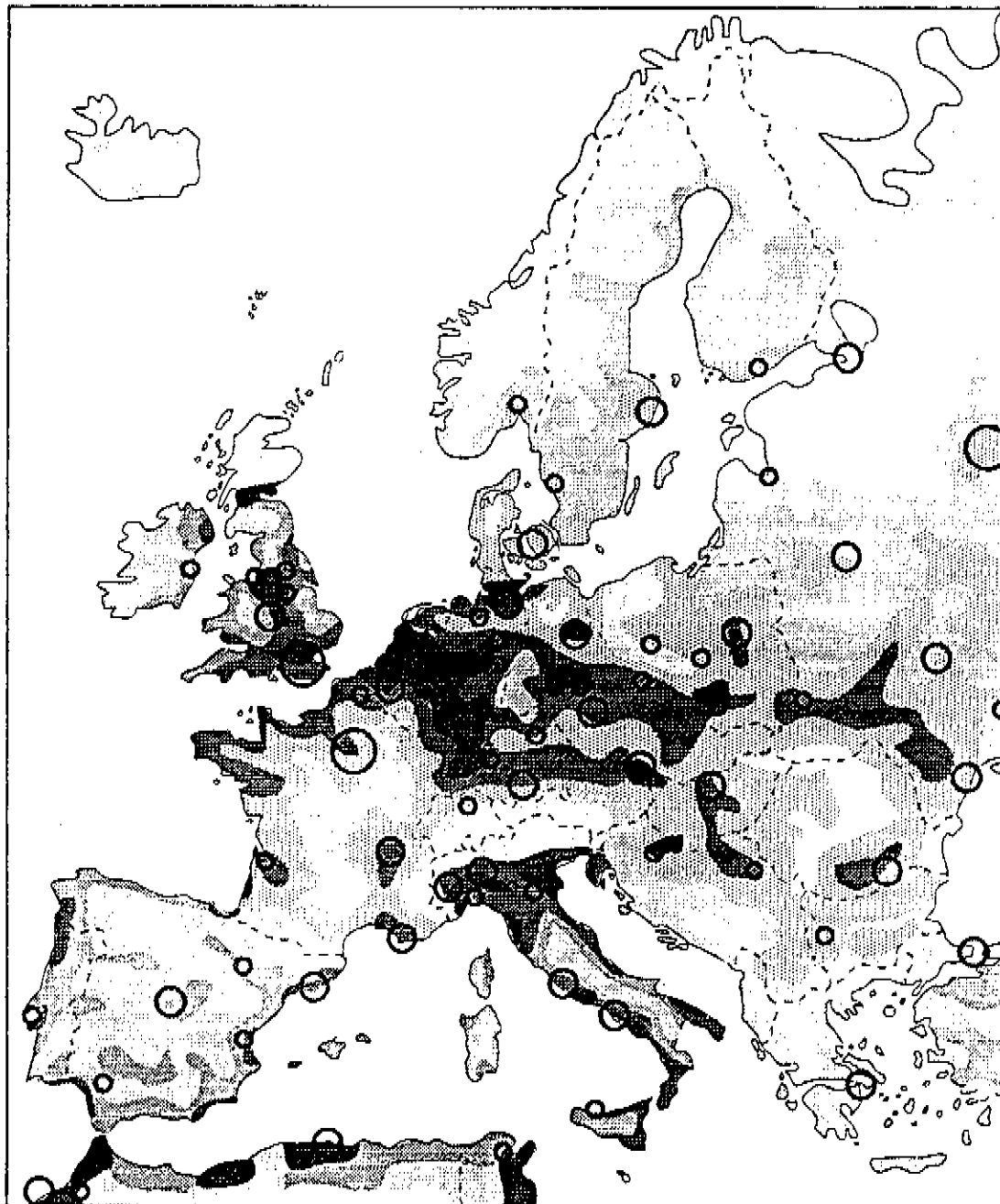
(Source: OXIDATE)

Fig. 3. SO_2 concentrations in Weimar, 1985-1987



Dotted line: daily 1-h maximum SO_2 concentration
Solid line : daily average SO_2 concentration

Fig. 4. Population density in Europe



Inhabitants per km²

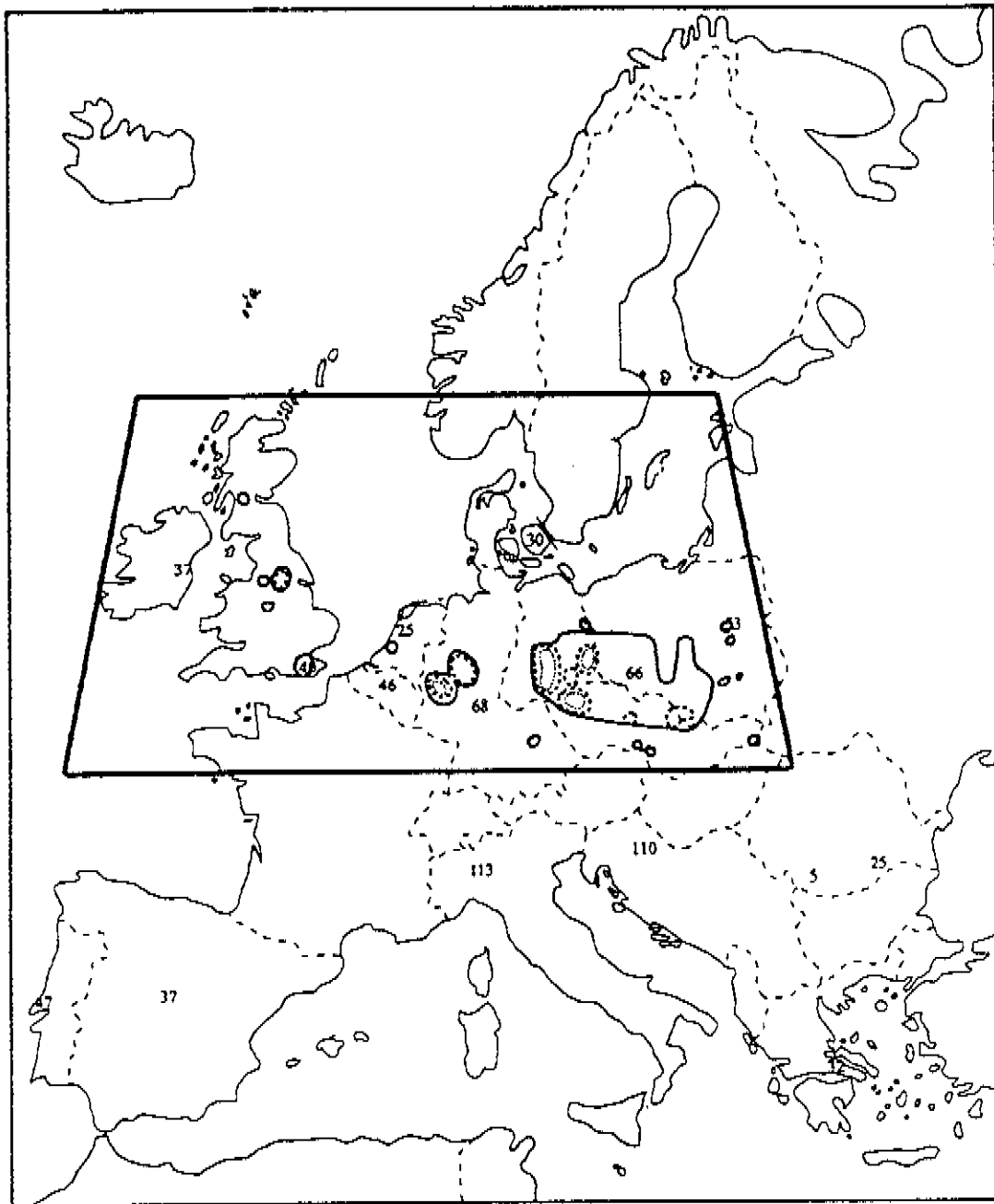
<10
10-50
50-100

100-200
> 200

○ agglomeration with >5 mln inhabitants
○ agglomeration with 1 mln - 5 mln inhabitants
○ city with 500.000 - 1 mln inhabitants

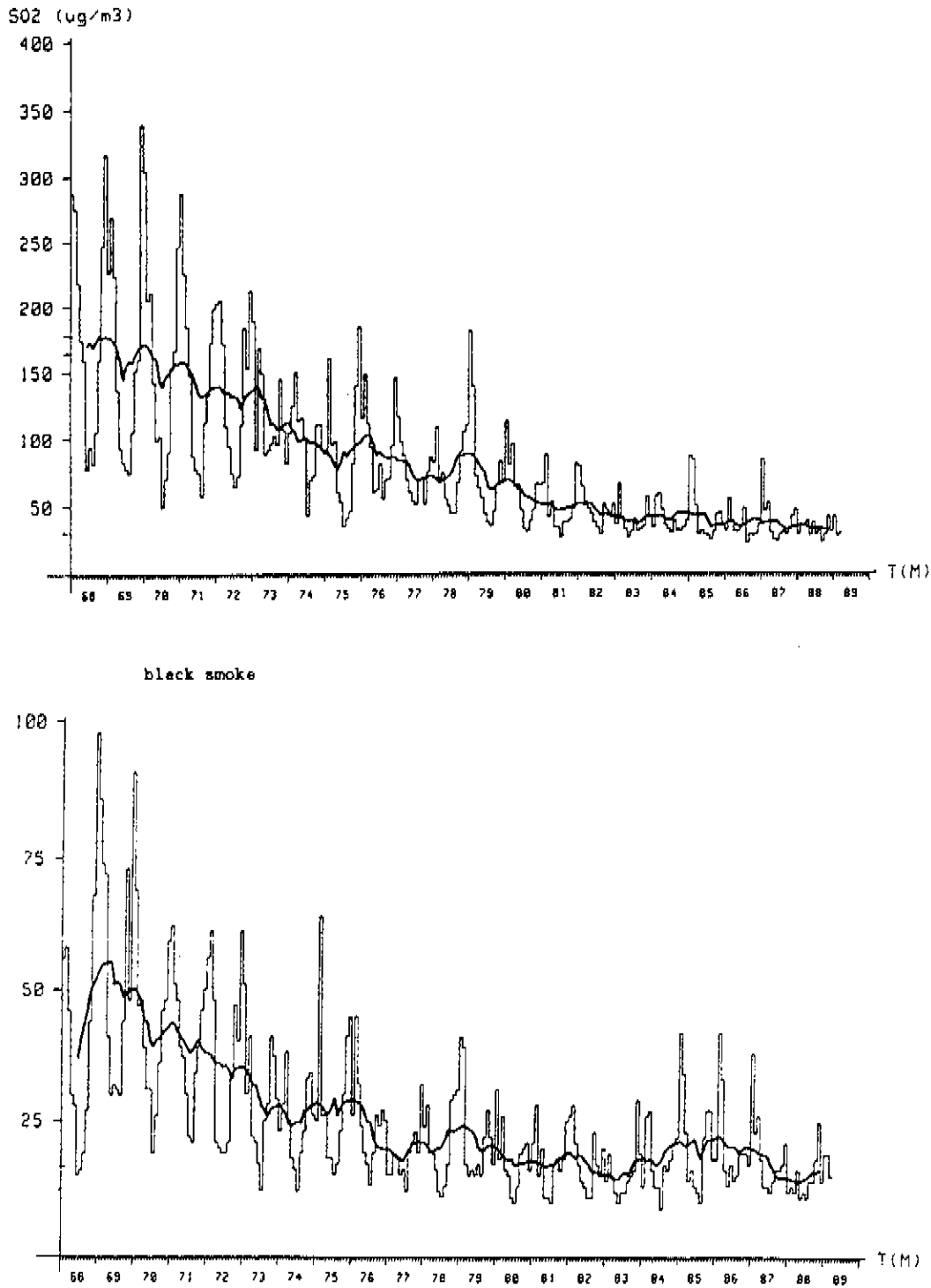
(Source: De grote Bosatlas 1981)

Fig. 5. Calculated 98-percentile of 24-h SO₂ concentrations in the PHOXA area (base year: 1982)



— limits of PHOXA area
numbers GEMS 98-percentile of SO₂ concentration measurements (μg/m³), 1985
..... 750 μg/m³
----- 500 μg/m³
———— 250 μg/m³

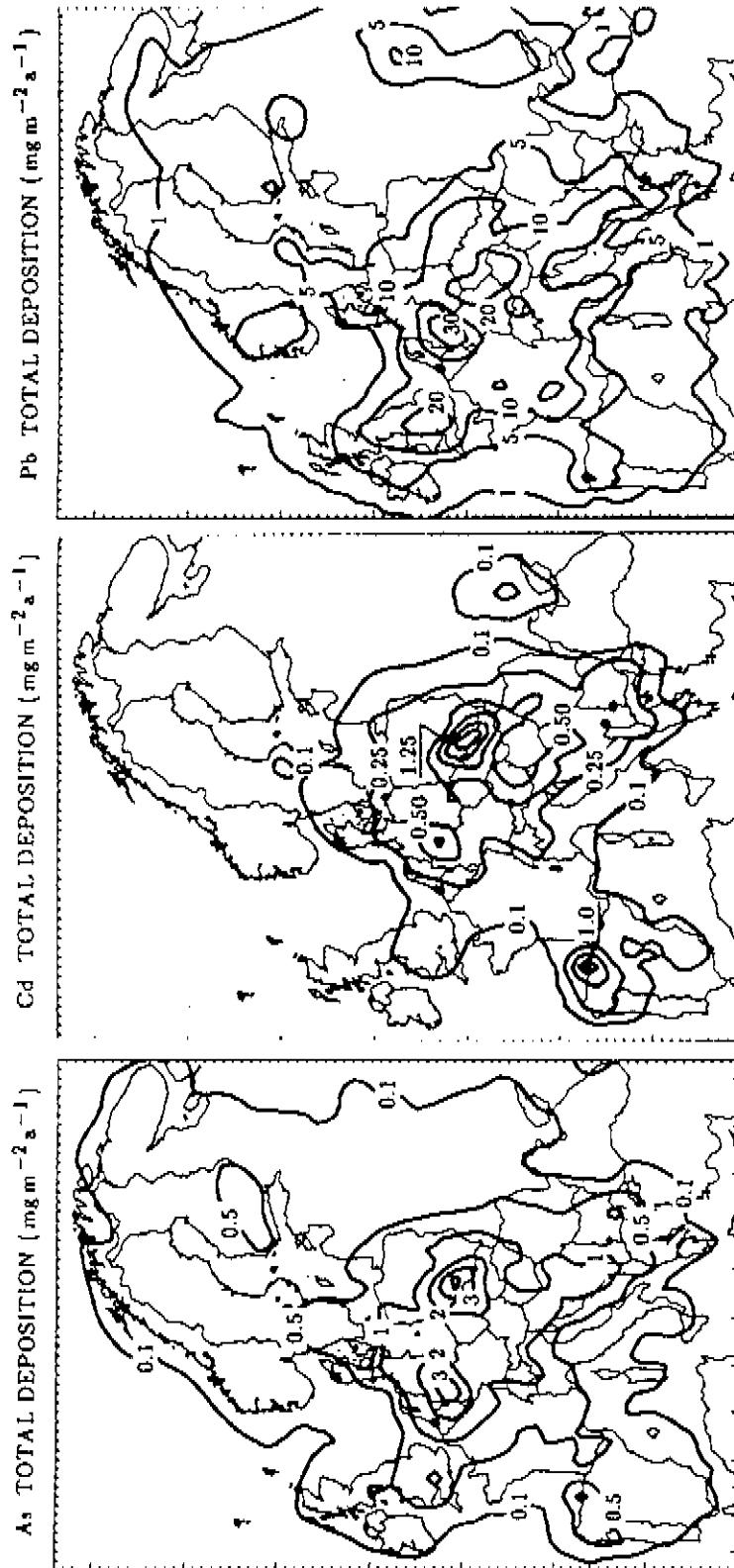
Fig. 6. SO_2 and black smoke concentrations in Brussels, 1968-1988



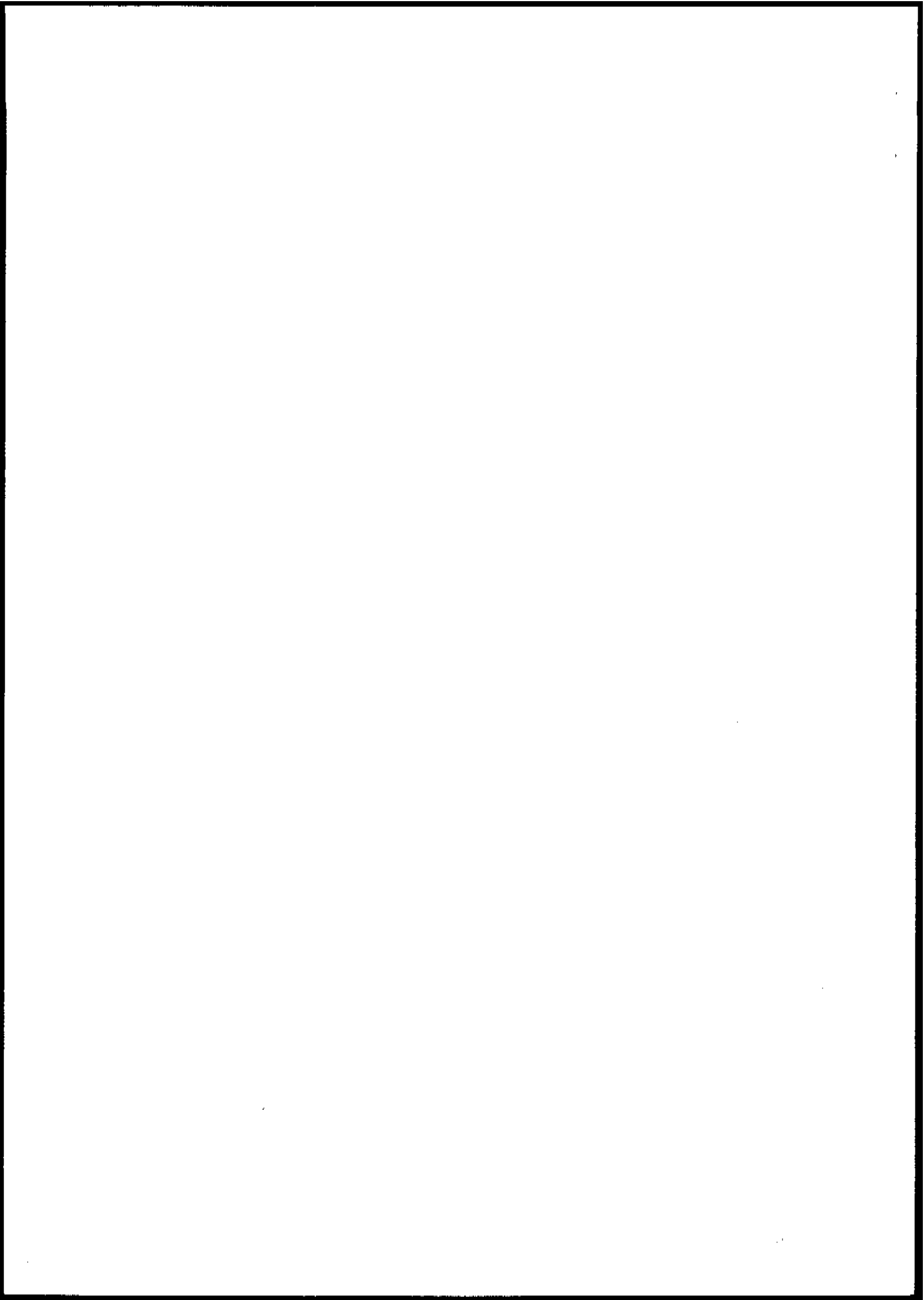
Thin line : monthly average concentration
Thick line: 12-months moving average concentration

(Source: IHE, 1990)

Fig. 7. Computed total deposition contours of As, Cd and Pb



(Source: IIASA, 1990)



ANNEX 1

LIST OF EXPERTS

First Working Group, Research Triangle Park, NC, USA, 6-8 June 1990

- Dr Miroslav Cikrt, Centre of Industrial Hygiene and Occupational Diseases,
Institute of Hygiene and Epidemiology, Prague, Czech and Slovak Federal
Republic
- Mr E. Gardner-Evans, Atmospheric Research and Exposure Assessment Laboratory,
US Environmental Protection Agency (EPA), Research Triangle Park, NC, USA
- Dr Robert Coyer, Professor and Chairman, Department of Pathology,
Faculty of Medicine, University of Western Ontario, London, ON, Canada
- Dr Judith Graham, Associate Director, Environmental Criteria and Assessment
Office, US Environmental Protection Agency (EPA), Research Triangle Park,
NC, USA
- Dr Lester D. Grant, Director, Environmental Criteria and Assessment Office,
US Environmental Protection Agency, Research Triangle Park, NC, USA
- Dr Arnim Hasse, Head, Section for Environmental Health Effects, Federal
Environmental Agency, Berlin, Federal Republic of Germany
- Dr Michael D. Lebowitz, Professor of Internal Medicine and Associate Director,
Division of Respiratory Sciences, College of Medicine, Health Sciences
Center, University of Arizona, Tucson, AZ, USA
- Dr Morton Lippmann, Professor of Environmental Medicine, Institute of
Environmental Medicine, New York University Medical Center, Tuxedo, NY,
USA
- Dr Magnus Piscator, Professor, Department of Environmental Hygiene,
The Karolinska Institute, Stockholm, Sweden
- Dr Michiel Roemer, Centre for Medical Technology, Institute of Applied
Scientific Research (TNO), Delft, Netherlands
- Dr Peter J.A. Rombout, Head, Department of Inhalation Toxicology, Laboratory
for Toxicology, National Institute of Public Health and Environmental
Hygiene (RIVM), Bilthoven, Netherlands
- Dr Jerzy A. Sokal, Head, Industrial Toxicology Division, Institute of
Occupational Medicine, Lodz, Poland.
- Dr Jan A.J. Stolwijk, Professor, Department of Epidemiology and Public Health,
Yale University School of Medicine, New Haven, CT, USA

Reviewers by Correspondence, June 1990

Dr Paul J. Lioy, Professor of Environmental and Community Medicine and Director, Division of Exposure Measurement and Assessment, Robert Wood Johnson Medical School, University of Medicine and Dentistry of New Jersey, Piscataway, New Jersey, USA

Dr Roger O. McClellan, President, Chemical Industry Institute of Toxicology (CIIT), Research Triangle Park, NC, USA

Mr Mark Rayzenne, Scientist, Bureau of Chemical Hazards, Environmental Health Directorate, Health and Welfare Canada, Ottawa, ON, Canada

Second Working Group, Bilthoven, Netherlands, 9-12 July 1990

Dr Leendert van Bree, Senior Toxicologist, National Institute of Public Health and Environmental Hygiene (RIVM), Bilthoven, Netherlands

Dr Bert Brunekreef, Associate Professor, Department of Environmental and Tropical Health, Wageningen Agricultural University, Wageningen, Netherlands

Mr Hans C. Eerens, Scientist, Laboratory for Air Research, National Institute of Public Health and Environmental Hygiene (RIVM), Bilthoven, Netherlands

Dr Norbert Englert, Team Leader on Air Pollution Neurophysiology, Air Hygiene Department, Institute of Water, Soil and Air Hygiene, Federal Health Office, Berlin, Federal Republic of Germany

Dr Arnim Hasse, Berlin, Federal Republic of Germany

Dr Erik Lebret, Coordinator, Environmental Epidemiology, Department of Epidemiology, National Institute of Public Health and Environmental Hygiene, (RIVM), Bilthoven, Netherlands

Mr Marten Marra, Scientist, Department of Inhalation Toxicology, Laboratory for Toxicology, National Institute of Public Health and Environmental Hygiene (RIVM), Bilthoven, Netherlands

Dr Michiel Roemer, Delft, Netherlands

Dr Peter Rombout, Bilthoven, Netherlands

Dr Jerzy A. Sokal, Lodz, Poland

Dr Jan A.J. Stolwijk, New Haven, CT, USA

Dr Michael J. Suess, Regional Officer for Environmental Health Hazards, WHO Regional Office for Europe, Copenhagen, Denmark

Final Drafting Committee, Bilthoven, Netherlands, 13-16 July 1990

Dr Leendert van Bree, Bilthoven, Netherlands

Dr Erik Lebret, Bilthoven, Netherlands

Mr Marten Marra, Bilthoven, Netherlands

Dr Peter Rombout, Bilthoven, Netherlands

Dr Michael J. Suess, Copenhagen, Denmark