WORLD HEALTH ORGANIZATION
EUROPE

HEALTH ASPECTS OF AIR POLLUTION

RESULTS FROM THE WHO PROJECT "SYSTEMATIC REVIEW OF HEALTH ASPECTS OF AIR POLLUTION IN EUROPE"

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ABSTRACT

This report summarizes the most recent information on the health effects of air pollution. It is based on the results of a comprehensive review of scientific evidence organized by the World Health Organization in support of air pollution policy development in Europe, and in particular the European Commission's Clean Air for Europe (CAFE) programme. The review indicates that air pollution at current levels still poses a considerable burden on health in Europe. Many different adverse effects have been linked to exposure to air pollution, including an increased risk of cardiopulmonary disease and a reduction in life expectancy of a year or more for people living in European cities. Some of these effects occur at very low concentrations that were previously considered safe. Taken together, the evidence is sufficient to strongly recommend further policy action to reduce levels of air pollutants, including particulates, nitrogen dioxide and ozone. It is reasonable to assume that a reduction in air pollution will lead to considerable health benefits.

Keywords

AIR POLLUTANTS, ENVIRONMENTAL – adverse effects
AIR POLLUTION – prevention and control
RISK ASSESSMENT
HEALTH POLICY
ENVIRONMENTAL EXPOSURE
CHILD WELFARE
EPIDEMIOLOGIC STUDIES
META-ANALYSIS
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FOREWORD

Unlimited and free access to clean air of acceptable quality is a fundamental human necessity and right.

The lung is a critical interface between the environment and the human body. An average person takes about 10 million breaths a year, and toxic substances in air can easily reach the lung and other organs where they can produce harmful effects. An adequate understanding of the nature and magnitude of the effects of different air pollutants on health is an essential step in developing successful policies to reduce these risks.

Recent studies suggest that outdoor air pollution still poses a considerable threat to human health in Europe, leading to greater morbidity and shorter life expectancy. This report highlights some of the main findings of the WHO project "Systematic review of health aspects of air pollution in Europe", which provides essential input to EU policy-making on air quality, in particular the Clean Air for Europe (CAFE) programme of the European Commission.

More than 80 leading experts in the field of air pollution research, mainly from Europe and North America, were actively involved in the systematic review. This project is a further example of the role of WHO in providing impartial, evidence-based advice to policy-makers that will allow for an effective improvement in the health and quality of life of the citizens of Europe.

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1. THE PROBLEM

Air pollution significantly affects the health of Europeans

SHOULD WE STILL BE CONCERNED ABOUT AIR POLLUTION?

Adverse effects of different pollutants on human health have been well documented in Europe and other parts of the world. These include many diseases and an estimated reduction in life expectancy of a year or more for people living in European cities. There is also evidence of increased infant mortality in highly polluted areas. Concerns about these health effects have led to the implementation of regulations to reduce emissions of harmful air pollutants and their precursors at international, national, regional and local levels. Other measures – while necessary to further reduce the health effects of air pollution – are becoming increasingly expensive. There is thus a growing need for accurate information on the effect of air pollution on health as a basis for designing scientific, effective and well targeted strategies to reduce these effects.

2. DEVELOPMENT OF EUROPEAN AIR QUALITY POLICIES AND ADVICE FROM WHO

WHAT ARE THE OVERALL TARGETS FOR CLEAN AIR POLICY?

In July 2002 the European Parliament and the Council adopted Decision 1600/2002/EC on the Sixth Community Environment Action Programme (Sixth EAP). This Programme sets out the key environmental objectives to be attained in the European Community. It also establishes, where appropriate, targets and timetables for meeting these objectives. One of the objectives of the Sixth EAP (Article 2) is to establish "... a high level of quality of life and social well being for citizens by providing an environment where the level of pollution does not give rise to harmful effects on human health …" (*1*). In Article 7, objectives and priority areas for action on environment and health and quality of life are further specified. It states that the objectives – including achieving levels of pollution that do not give rise to harmful effects on human health – "should be pursued … taking into account relevant World Health Organization (WHO) standards, guidelines and programmes" (*1*).

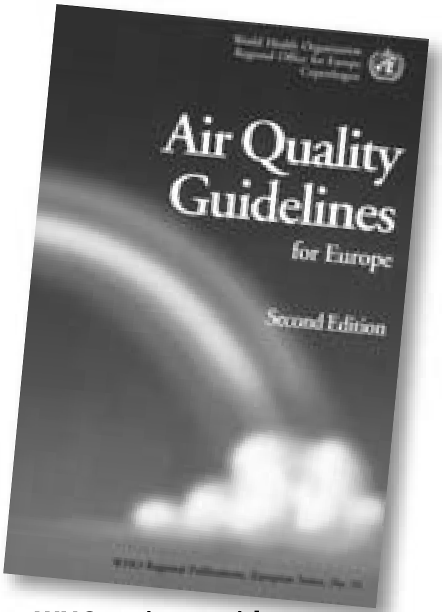
European Community targets for air pollution – no significant negative effects on health

WHAT IS THE CLEAN AIR FOR EUROPE (CAFE) PROGRAMME?

The activities of the European Commission to implement the Sixth EAP currently take place within the Clean Air for Europe (CAFE) programme. This programme of technical analysis and policy development will lead to the adoption of a thematic strategy on air pollution under the Sixth EAP. The major elements of the CAFE programme are outlined in Communication COM(2001)245 (*2*). The programme, launched in early 2001, aims to develop long-term, strategic and integrated policy advice to protect against significant negative effects of air pollution on human health and the environment.

WHAT IS THE ROLE OF WHO?

WHO has in recent years investigated and reviewed the effects of different environmental hazards on human health. The European Centre for Environment and Health of WHO's Regional Office for Europe has in particular investigated the health effects of ambient air pollution. The Regional Office published *Air quality guidelines for Europe* (AQG) in 1987 (*3*) and an updated second edition in 2000 (*4*). The aim of these guidelines is "... to provide a basis for protecting public health from adverse effects of air pollutants and for eliminating, or reducing to a minimum, those contaminants of air that are known or likely to be hazardous to human health and wellbeing" (*4*).



WHO reviews evidence and provides guidance

3. THE SYSTEMATIC REVIEW PROJECT AND ITS APPROACH

WHAT IS THE SYSTEMATIC REVIEW?

The WHO project "Systematic review of health aspects of air quality in Europe" (WHO systematic review) aims to provide the CAFE programme with a systematic, scientifically independent review of the health aspects of air quality in Europe. The project began in late 2001 and ran until the middle of 2004. The results of the review are described in a number of reports (see box). This report presents the summary of the main findings, while a more extensive discussion of the different items can be found in these other reports.

Main reports produced within the WHO systematic review project:

- *Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide* (*5*)
- *Meta-analysis of time-series studies and panel studies of particulate matter (PM) and ozone (O_3)* (*6*)
- *Health aspects of air pollution – answers to follow-up questions from CAFE* (*7*)
- *The effects of air pollution on children's health and development: a review of the evidence* (*8*)

The WHO systematic review is a project to provide input to policy development, in particular for CAFE

A Scientific Advisory Committee, consisting of ten independent experts in the field of air pollution and health, was established by WHO in 2001 to guide this review project.

To serve the needs of the CAFE programme effectively, it was decided to prepare major parts of the review reports as answers to policy-relevant questions. These questions were formulated by the CAFE secretariat at the European Commission in close collaboration with the CAFE Steering Group, which advises DG Environment of the Commission on the strategic direction of the CAFE programme. The approaches to answering the questions were rather complex. The procedure for preparing the report *Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide* (*5*) is shown in Fig. 1 as an example. WHO followed the guidelines provided in the document *Evaluation and use of epidemiological evidence for environmental health risk assessment* (*9*). In addition, much emphasis was placed on having a comprehensive review process. A large number of experts were invited to review the different drafts carefully and critically, and working group meetings were subsequently held to discuss the issues and to agree on the conclusions.

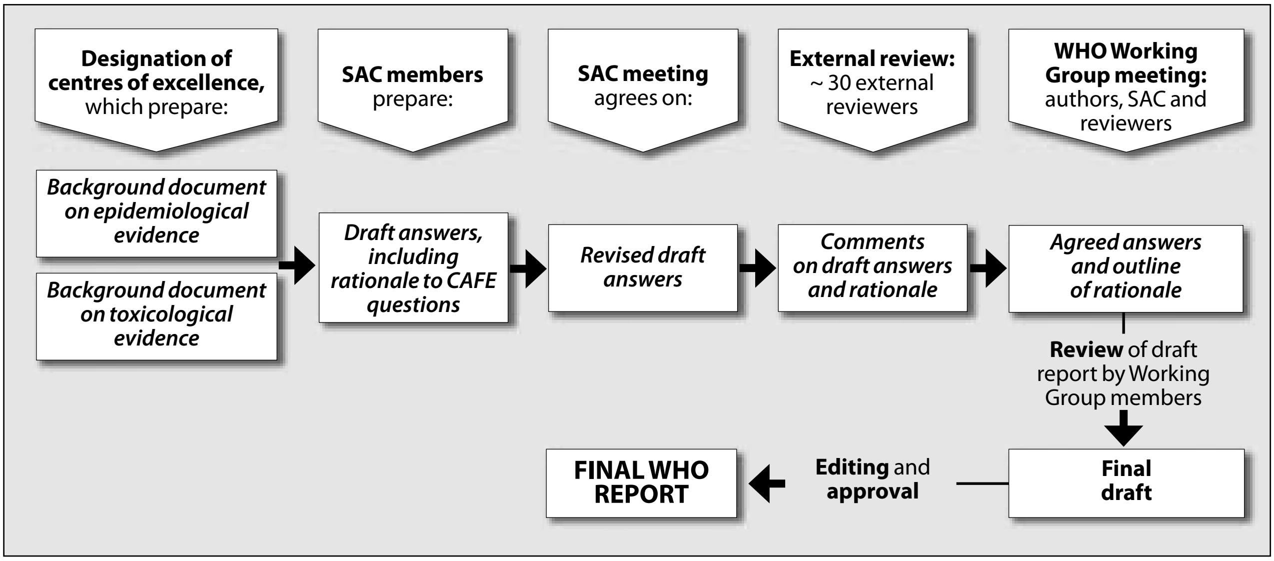


Fig. 1.
Schematic schedule of the preparation of the report *Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide*

WHAT ARE THE SOURCES OF INFORMATION?

An interdisciplinary approach was used

Carrying out a review of the effects on health of ambient air pollution is a challenging task, since a remarkably large body of evidence has to be assessed. For particulate matter especially, hundreds of new scientific papers have been published in the last few years, addressing aspects such as exposure and toxicological and epidemiological findings on adverse health effects. There has also been substantial technological and methodological progress in the research field of air pollution and health in recent years, including multicentre studies and the use of concentrated ambient particles (CAPs) in experimental studies on humans and animals. The review assessed information from different research disciplines, including observational epidemiology, controlled human exposures to pollutants, animal toxicology and in vitro mechanistic studies. Each of these approaches has strengths and weaknesses, and an integrated synthesis of all these different sources of information led to the conclusions presented below.

WHICH POLLUTANTS ARE ADDRESSED?

Focus on PM, ozone and nitrogen dioxide

Ambient air pollution consists of a highly variable, complex mixture of different substances, which may occur in the gas, liquid or solid phase. Several hundred different components have been found in the troposphere, many of them potentially harmful to human health and the environment. Nevertheless, the systematic review focused on three pollutants: particulate matter (PM), ozone and nitrogen dioxide, as requested by the CAFE Steering Group. This is not to imply that other substances do not pose a considerable threat to human health and the environment at levels present in Europe nowadays. Nevertheless, either have the effects of other substances recently been reviewed or the conclusions from the *Air quality guidelines for Europe* (*4*) were considered to be generally still valid. It should also be mentioned that PM in itself is a complex mixture of solid and liquid constituents, including inorganic salts such as nitrates, sulfates and ammonium and a large number of carbonaceous species (elemental carbon and organic carbon).

Thus PM implicitly covers a number of different chemical pollutants emitted by various types of source.

A strict methodology for the review

HOW WAS OBJECTIVITY ENSURED?

To derive robust and unbiased conclusions regardless of the uncertainties, the review followed the WHO guideline document *Evaluation and use of epidemiological evidence for environmental health risk assessment* (*9*). The project (*a*) developed and followed a specific protocol for the review; (*b*) identified and assessed the validity of the relevant studies; (*c*) conducted a systematic overview of evidence from multiple studies, including formal meta-analysis; and (*d*) based its conclusions on the critical scientific judgement of a wide range of experts working in various disciplines related to the assessment of the effects of air pollution on health. According to WHO rules, a Declaration of Interests form had to be signed by all experts involved in the review.

4. RESULTS – HEALTH EFFECTS OF PM, OZONE AND NITROGEN DIOXIDE

WHICH EFFECTS ARE CAUSED BY AIR POLLUTION?

Exposure to ambient air pollution has been linked to a number of different health outcomes, starting from modest transient changes in the respiratory tract and impaired pulmonary function, continuing to restricted activity/reduced performance, emergency room visits and hospital admissions and to mortality. There is also increasing evidence for adverse effects of air pollution not only on the respiratory system, but also on the cardiovascular system. This evidence stems from studies on both acute and chronic exposure. The most severe effects in terms of the overall health burden include a significant reduction in life expectancy of the average population by a year or more, which is linked to the long-term exposure to high levels of air pollution with PM. A selection of important health effects linked to specific pollutants is summarized in Table 1.

Main health effects of air pollution – from mild symptoms to death

Table 1. Important health effects associated with exposure to different air pollutants

Pollutant	Effects related to short-term exposure	Effects related to long-term exposure
Particulate matter	• Lung inflammatory reactions • Respiratory symptoms • Adverse effects on the cardiovascular system • Increase in medication usage • Increase in hospital admissions • Increase in mortality	• Increase in lower respiratory symptoms • Reduction in lung function in children • Increase in chronic obstructive pulmonary disease • Reduction in lung function in adults • Reduction in life expectancy, owing mainly to cardiopulmonary mortality and probably to lung cancer
Ozone	• Adverse effects on pulmonary function • Lung inflammatory reactions • Adverse effects on respiratory symptoms • Increase in medication usage • Increase in hospital admissions • Increase in mortality	• Reduction in lung function development
Nitrogen dioxide[a]	• Effects on pulmonary function, particularly in asthmatics • Increase in airway allergic inflammatory reactions • Increase in hospital admissions • Increase in mortality	• Reduction in lung function • Increased probability of respiratory symptoms

[a] In ambient air, nitrogen dioxide serves as an indicator for a complex mixture of mainly traffic-related air pollution.

WILL A REDUCTION IN AIR POLLUTION IMPROVE HEALTH?

The body of evidence on the effects on health of air pollution at levels currently common in Europe has strengthened considerably over the last few years. Both epidemiological and toxicological evidence have contributed to this strengthening. The latter provides new insights into possible mechanisms for the hazard-

Reducing pollutant levels brings significant health benefits

ous effects of air pollutants on human health and complements the large body of epidemiological evidence, which shows, for example, consistent associations between daily variations in air pollution and certain health outcomes. One of the crucial questions – both for the scientific community and for policy-makers – is whether these associations are causal and, if so, which agent(s) involved in the air pollution mixture play a crucial role in the effects. Only if relationships are shown to be causal can it be assumed that a reduction in pollution will reduce health effects. The results of this review strongly suggest that it is indeed reasonable to assume that a further reduction in air pollution will lead to health benefits. This is also in line with recent "intervention studies" that have demonstrated health benefits following the reduction of pollution levels under various circumstances.

WHICH POPULATION GROUPS ARE AT HIGH RISK?

A number of groups within the population have potentially higher vulnerability to the effects of exposure to air pollutants. These are those who are innately more susceptible to the effects of exposure to air pollutants than others, those who become more susceptible (for example, as a result of environmental or social factors or personal behaviour) and those who are simply exposed to unusually large amounts of air pollutants. Members of the last group are vulnerable by virtue of exposure rather than as a result of individual susceptibility.

The elderly, children and those with underlying disease are potentially at higher risk

Unborn and very young children seem particularly sensitive to some pollutants (see Chapter 5). Other groups that are more sensitive include the elderly, those with cardiorespiratory disease, those who are exposed to other toxic materials that add to or interact with air pollutants, and the socioeconomically deprived. When compared with healthy people, those with respiratory disorders (such as asthma or chronic bronchitis) may react more strongly to a given exposure, either as a result of increased responsiveness to a specific dose and/or as a result of a larger internal dose of some pollutants than in normal individuals exposed to the same concentration. Increased particle deposition and retention have been demonstrated in the airways of people suffering from obstructive lung disease.

ARE THERE SAFE POLLUTION LEVELS?

Health is affected even at low PM and ozone levels

In the past, the concept of no-effect thresholds played an important role in deriving air quality guidelines. The existence of such thresholds implies no effects of increasing air pollution until a "threshold" concentration is surpassed, at which stage risk rises. Thresholds are in principle an appealing concept that has also been used in defining air quality policies, such as in justifying the numerical value of air quality limit values. Nevertheless, recent epidemiological studies investigating large populations have been unable consistently to establish such threshold levels, in particular for PM and ozone. Rather, they consistently show effects at the levels studied. These findings also imply that the current WHO air quality guideline for ozone of 120 $\mu g/m^3$ as an eight-hour mean value does not represent a level below which no adverse effects are expected. Consequently, the threshold concept is probably elusive at a population level for these pollutants. This is almost certainly because there are inevitably large differences in individual susceptibilities in large populations. Instead of thresholds, exposure/concentration–response relationships for different health end-points provide more realistic information for taking effective action to reduce adverse effects on human health.

ARE THE CURRENT LIMIT VALUES SUFFICIENT TO ENSURE NO ADVERSE HEALTH EFFECTS?

The recent WHO review reconfirmed that exposure to particulate matter and ozone poses a significant risk to human health at concentration levels common in Europe today. Thus, it can be concluded that further reductions in air pollution will have significant health benefits, even in regions where levels are well below current European Union (EU) limit values for PM and target values for ozone. Current air quality standards are to a large extent based on the concept of an effect threshold, below which significant health effects are not likely to occur. As stated above, no such threshold is evident for PM and ozone. Therefore, even if the limit /target value is not exceeded significant health impacts, including a substantial reduction in life expectancy, are to be expected. Conversely, a reduction in pollutant concentrations below the current standards should result in health benefits.

The current EU limit/ target values for PM and ozone do not provide complete health protection

PARTICULATE MATTER (PM)

WHAT IS PM?

The term particulate matter (PM) is used to describe airborne solid particles and/or droplets. These particles may vary in size, composition and origin (Fig. 2). Several different indicators have been used to characterize ambient PM.

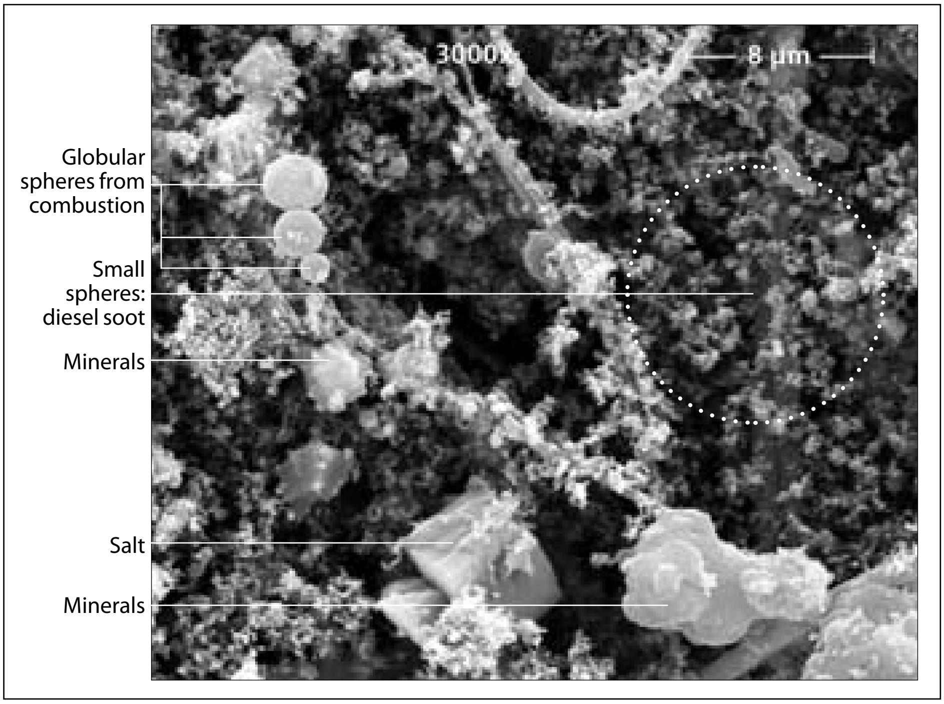


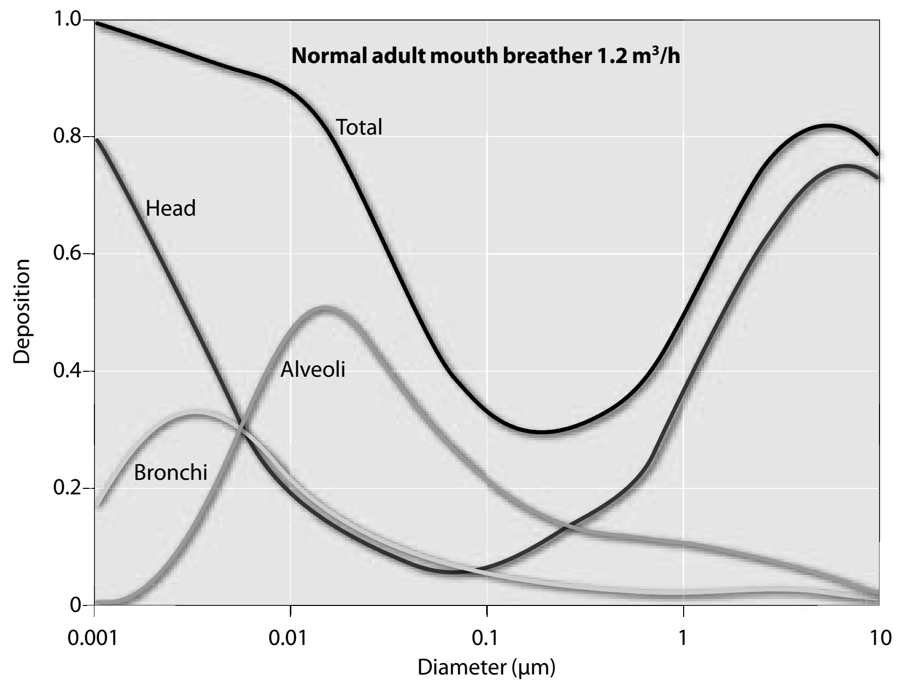
Fig. 2.
Electron micrograph of PM sampled on a filter near a street; diesel soot (small grey spheres) dominates the sample

Source: C. Trimbacher, Umweltbundesamt Wien.

Particulate matter is a complex mixture of various particles of different sizes

Classification by size is quite common because size governs the transport and removal of particles from the air and their deposition within the respiratory system, and is at least partly associated with the chemical composition and sources of particles. Based on size, urban PM tends to be divided into three principal groups: coarse, fine and ultrafine particles. The border between the coarse and fine particles usually lies between 1 μm and 2.5 μm, but is usually fixed by convention at 2.5 μm in aerodynamic diameter ($PM_{2.5}$) for measurement purposes. The border between fine and ultrafine particles lies at about 0.1 μm. PM_{10} is used to describe particles with an aerodynamic diameter smaller than 10 μm. The particles contained in the PM_{10} size fraction may reach the upper part of the airways and lung. Fig. 3 shows schematically where particles are deposited in the respiratory tract, depending on their size. Smaller particles (in particular $PM_{2.5}$) penetrate more deeply into the lung and may reach the alveolar region. Ultrafine particles contribute only slightly to PM_{10} mass but may be important from a health point of view because of the large numbers and high surface area. They are produced in large numbers by combustion (especially internal combustion) engines.

Fig. 3.
Deposition probability of inhaled particles in the respiratory tract according to particle size



Source: W.G. Kreyling, adapted from International Commission on Radiological Protection.

ARE ALL PM COMPONENTS EQUALLY DANGEROUS?

As stated above, PM in ambient air has various sources. In targeting control measures, it would be important to know if PM from certain sources or of a certain composition gave rise to special concern from the point of view of health, for example owing to high toxicity. The few epidemiological studies that have addressed this important question specifically suggest that combustion sources are particularly important for health. Toxicological studies have also pointed to primary combustion-derived particles as having a higher toxic potential. These particles are often rich in transition metals and organic compounds, and also have a relatively high surface area. By contrast, several other single components of the PM mixture (e.g. ammonium salts, chlorides, sulfates, nitrates and wind-blown dust such as silicate clays) have been shown to have a lower toxicity in laboratory studies. Despite these differences found among constituents studied under laboratory conditions, it is currently not possible to quantify the contributions from different sources and different PM components to the effects on health caused by exposure to ambient PM. Nevertheless, it seems reasonable to include in abatement efforts those sources/constituents that have been shown to be critical, such as emissions from diesel engines.

Particles generated in combustion processes are of particular concern

WHICH INDICATORS SHOULD BE USED TO ASSESS AND REGULATE PM?

Many studies have found that fine particles (usually measured as $PM_{2.5}$) have serious effects on health, such as increases in mortality rates and in emergency hospital admissions for cardiovascular and respiratory reasons. Thus there is good reason to reduce exposure to such particles. Coarse particles (usually defined as the difference between PM_{10} and $PM_{2.5}$) seem to have effects on, for example, hospital admissions for respiratory illness, but their effect on mortality is less clear. Nevertheless, there is sufficient concern to consider reducing exposure to coarse particles as well as to fine particles. Up to now, coarse and fine particles have been evaluated and regulated together, as the focus has been on PM_{10}. However, the two types have different sources and may have different effects, and tend to be poorly correlated in the air. The systematic review therefore recommended that consideration be given to assessing and controlling coarse as well as fine PM. Similarly, ultrafine particles are different in composition, and probably to some extent in effect, from fine and coarse particles. Nevertheless, their effect on human health has been insufficiently studied to permit a quantitative evaluation of the risks to health of exposure to such particles.

PM mass is an appropriate indicator of the effects of PM on health

Despite much effort, it has not yet been possible to identify with confidence which chemical constituents of PM are primarily responsible for the different effects on health. In population studies, effects have been related to sulfates, soot and acids, independently of particle mass indicators such as PM_{10} and $PM_{2.5}$. On the other hand, experimental studies have not been able to show that sulfates, and substances such as nitrates and sea salt, are harmful in realistic concentrations. Some studies have focused on specific sources, and a number have shown that air pollution from traffic in general is related to adverse effects on health. The evidence is currently insufficient, however, to recommend that PM mass indicators should be replaced or supplemented by PM composition indicators in evaluating health effects and regulating air pollution mixtures.

ARE ACUTE OR CHRONIC EFFECTS THE MAIN CONCERN?

The systematic review confirmed that the public health significance of the long-term effects of exposure to PM clearly outweighs that of the short-term effects.

Long-term exposure to PM is the main concern, but acute effects are also considerable

Nevertheless, the effects of short-term exposure to PM have been documented in numerous time-series studies,[1] many of them conducted in Europe; these indicated large numbers of outcomes, such as attributable deaths and hospital admissions for cardiovascular and respiratory conditions. Both short-term (24 hours) and long-term (annual average) guidelines are therefore recommended.

OZONE

SHOULD WE FOCUS ON SUMMER SMOG OZONE PEAKS?

Ozone peaks are important, but levels must also be reduced during the entire (summer) season

Traditionally, the interest of the general public and policy-makers in ambient ozone has focused on high peak levels, which usually occur during hot, dry periods in the summer. Recent evidence suggests, however, that ozone levels lower than those experienced during episodes of "summer smog" may have considerable effects on human health. Time-series studies have demonstrated linear or near-linear relationships between day-to-day variations in ozone levels and health end-points even at low levels of exposure. As there are usually many more days with mildly elevated concentrations than days with very high concentrations, the largest burden on public health may be expected with the former rather than the latter. Consequently, abatement policies should not only focus on the few days with high peak concentrations but should aim to reduce ozone levels throughout the summer season.

WHAT IS THE APPROPRIATE AVERAGING TIME FOR A GUIDELINE?

Eight hours is the preferred averaging time for an ozone guideline

For short-term exposure, it is clear that effects increase with time (e.g. 6–8 hours for respiratory function effects and lung inflammation). Thus, an 8-hour averaging time is preferable to a 1-hour averaging time. The relationship between long-term ozone exposure and health effects is not yet sufficiently understood to allow a long-term guideline to be established.

NITROGEN DIOXIDE

SHOULD WE KEEP THE AIR QUALITY GUIDELINE FOR NITROGEN DIOXIDE?

The WHO systematic review closely reviewed the scientific evidence in support of the current WHO air quality guideline value for nitrogen dioxide of 40 μg/m^3 as an annual mean. This value is of considerable practical importance, since it has been transformed into a binding air quality limit value in EU legislation (*10*). The review concluded that there is evidence from toxicological studies that long-term exposure to nitrogen dioxide at concentrations higher than current ambient concentrations has adverse effects. Nevertheless, uncertainty remains about the significance of nitrogen dioxide as a pollutant with a direct impact on human health at current ambient air concentrations in the EU, and there is still no firm basis for selecting a particular concentration as a long-term guideline for nitrogen dioxide. In recent epidemiological studies of the effects of combustion-related (mainly

[1] These are studies that link daily variations in air pollution to specific health end-points such as hospital admissions or mortality.

traffic-generated) air pollution, nitrogen dioxide was shown to be associated with adverse health effects even when the annual average concentration was within a range that included 40 μg/m^3, the current guideline value. At this stage, there is no firm basis for establishing an alternative guideline, and it was therefore recommended that the WHO guideline value of 40 μg/m^3 as an annual mean should be retained or lowered. Moreover, the short-term guideline for nitrogen dioxide of 200 μg/m^3 is still justified.

The WHO air quality guideline value should be retained or lowered

5. RESULTS – FOCUS ON CHILDREN'S HEALTH

WHY ARE CHILDREN AT HIGH RISK?

Children are at high risk of suffering adverse effects of air pollution owing to their potentially high susceptibility. Important factors determining the susceptibility of children are summarized in Table 2.

Table 2. Factors determining the susceptibility of children to inhaled pollutants

Factors related to physiology	• Children breathe more per unit body weight than adults
	• Children have smaller airways and lungs
Factors related to metabolism	• Different rate of toxification and detoxification
Factors related to lung growth and development	• Vulnerability of developing and growing airways and alveoli
	• Immature host defence mechanisms
Factors related to time-activity patterns	• Time spent outdoors
	• Increased ventilation with play and exercise
Factors related to chronic disease	• High prevalence of asthma and other diseases
Factors related to acute disease	• High rates of acute respiratory infections

WHAT ARE THE RISKS FOR UNBORN AND NEWBORN CHILDREN?

There is evidence for effects of air pollution on infant mortality

Overall, there is evidence implicating air pollution in adverse effects on certain birth outcomes. A few studies have shown an association between exposure to air pollution and infant mortality; this effect is primarily due to respiratory deaths in the post-neonatal period and appears to be due mainly to PM. Studies on birth weight, pre-term births and intrauterine growth retardation also suggest a link with air pollution, although additional research is needed to confirm this.

DOES AIR POLLUTION INFLUENCE THE DEVELOPMENT OF THE LUNG?

Poor air quality affects lung development of children

The level of lung function is one of the strongest predictors of mortality in adults. Factors that affect development of lung function in children are potentially important in determining the level of lung function when these children grow up. Studies of lung function in children suggest that:

- living in areas of high air pollution is associated with lower lung function;
- long-term air pollution is associated with lower rates of lung function development;
- reduction in air pollution leads to improvements in lung function and/or lung growth rate; and
- acute exposure to high levels of air pollution is associated with (probably reversible) deficits in lung function.

These effects may account for only a small proportion of the average lung function. Nevertheless, a small shift in average lung function can yield a substantial increase in the fraction of children with “abnormally” low lung function. In addition, small changes in the population mean can reflect clinically relevant lung function deficits in a susceptible subgroup of the population.

IS THERE A RELATIONSHIP BETWEEN AIR POLLUTION AND RESPIRATORY INFECTIONS?

Analyses of outdoor air pollutants, including PM_{10}, nitrogen dioxide, sulfur dioxide and ozone, provide evidence that air pollution is associated with increased frequency and severity of upper and lower respiratory symptoms in children. Many of these effects are likely to be related to infections. There is also evidence for possible interactions between exposure to air pollution and infections, and that reducing air pollution could improve children’s health. The relative increases in the occurrence of infections are mainly small, but the number of affected children in a population is high.

Air pollution is associated with increased upper and lower respiratory symptoms in children

WHAT ARE THE EFFECTS OF AIR POLLUTION ON ASTHMA?

Long-term exposure to several outdoor air pollutants – and in particular to traffic-generated pollution – seems to increase the prevalence and/or incidence of bronchitis, cough and deficits in lung function. These effects seem to be stronger in asthmatics. Nevertheless, there is currently only limited evidence that air pollution plays a significant role in the observed increased incidence of asthma, allergic rhinitis and atopic eczema. When the overall evidence of epidemiological studies is considered, air pollution seems to aggravate asthma, leading to an increase in symptoms, greater use of relief medication and a transient decline in lung function.

Air pollution may increase bronchitis and cough and aggravate asthma symptoms

IS THERE A LINK BETWEEN CHILDHOOD CANCER AND AIR POLLUTION?

The hypothesis that air pollution causes cancer in children has been studied almost entirely in relation to traffic-generated air pollution. There is no conclusive evidence that traffic-related air pollution at current levels leads to an increased risk of childhood cancer. Additional research is also needed to assess the effects of exposure to air pollution on cancer development in later life.

It is uncertain whether current levels of ambient air pollution contribute to cancer development in children

NEURODEVELOPMENTAL AND BEHAVIOURAL EFFECTS

High levels of airborne heavy metals such as lead and certain persistent organic pollutants (POPs) may cause neurodevelopmental and behavioural defects in children. However, intake routes other than inhalation (such as eating and drinking) are often more important for such substances, and the cumulative intake has to be considered.

6. RESULTS – TOWARDS THE QUANTIFICATION OF EFFECTS

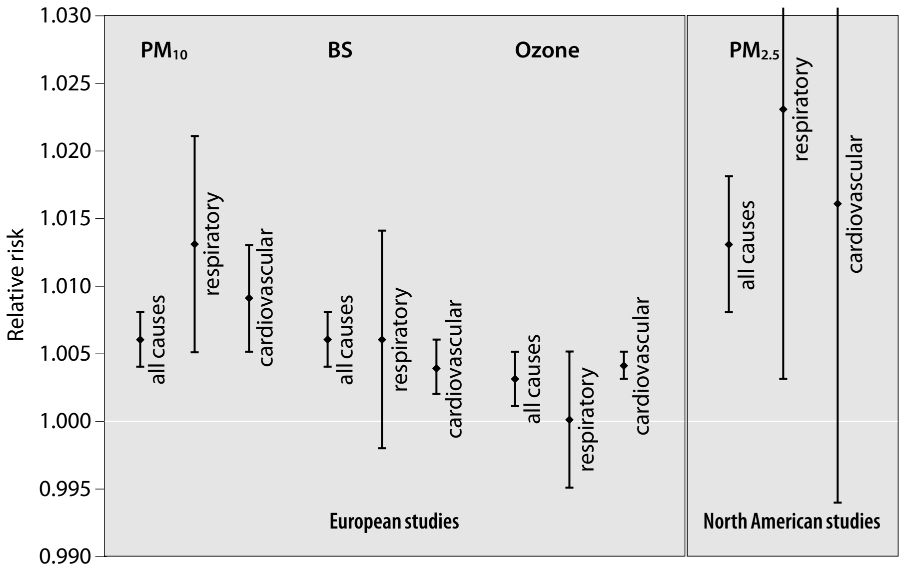
A combination of the evidence from health studies and air quality data allows one to estimate the burden of disease linked to air pollution

WHAT IS THE RELATIONSHIP BETWEEN DAILY CHANGES IN AIR POLLUTION AND HEALTH?

The quantification of health effects has become increasingly important in the development of air quality policy. For such analyses it is important to have accurate information on the concentration–response relationships for the effects investigated, i.e. on the relationship between the level of air pollution and the effect on health. A quantitative meta-analysis of peer-reviewed European studies was therefore conducted to obtain summary estimates for certain air pollutants and health effects. The data for these analyses came from a database of time-series studies developed at St George's Hospital Medical School at the University of London. The meta-analysis was performed at St George's according to a protocol approved in advance by a WHO Task Group. Using data from several European cities, the analysis confirmed statistically significant relationships between mortality and levels of PM and ozone in ambient air. Updated risk coefficients in relation to ambient exposure to PM and ozone were obtained for all-cause and cause-specific mortality and hospital admissions for respiratory and cardiovascular causes. Some results are shown in Fig. 4. The meta-analysis also included a thorough assessment of so-called publication bias.

Fig. 4.
Summary estimates for relative risks for mortality and different air pollutants

Relative risks for mortality end-points related to a 10- µg/m³ increase in pollution including 95% confidence intervals. *Left part:* PM_{10}, black smoke (BS) and ozone from European studies; *right part:* $PM_{2.5}$ from North American studies.



Note: There were not enough European results for a meta-analysis of effects of $PM_{2.5}$. The relative risk for this pollutant is from North American studies and is shown for illustrative purposes only.

CAN WE QUANTIFY THE EFFECTS?

Health impact assessment allows one to quantify the effects of exposure to an environmental hazard. It plays a central role in assessing the potential effects on health of different policies and measures, thereby providing a basis for decision-making. A detailed knowledge of several factors is a required for any such assessment.

- The underlying health hazard has to be characterized. Since changes in the magnitude of a hazard are linked to changes in effects, there should be sufficient evidence to assume a causal link between the exposure to the pollutant and the health end-point in question. As stated above, the systematic review provided convincing evidence that the effects observed in epidemiological studies are caused by exposure to air pollution.
- Exposure–response functions have to be established. The systematic review established concentration–response functions for several health end-points linked to exposure to PM and ozone.
- The exposure of the population to the pollutant in question has to be assessed. Crucial information on exposure to air pollutants is provided not only by ambient air quality monitoring but also by modelling. Air quality modelling is particularly important in linking pollution levels to emission sources. Modelling of ambient air quality on a European scale is carried out under the European Monitoring and Evaluation Programme (EMEP) programme of the Convention on Long Range Transboundary Air Pollution (*11*) and the City Delta project, which is led by the Joint Research Centre of the European Commission (*12*). This comprehensive information will be used to quantify the health benefits of various emission reduction scenarios.

The risk of adverse health effects increases steadily with rising air pollution levels

CAN WE ESTIMATE THE EFFECT OF LONG-TERM EXPOSURE TO PM ON MORTALITY?

If long-term exposure to a specific pollutant is linked to certain health effects, cohort studies[2] provide a basis for estimating effects on health caused by air pollution, such as a reduction in lifespan in a given population. This is the case for mortality linked to long-term exposure to PM. There are no results of comprehensive European studies currently available that provide risk estimates for increased mortality due to long-term exposure to PM mass. Therefore, an expert group led by WHO – the Joint UNECE/WHO-ECEH Task Force on Health Aspects of Long Range Transboundary Air Pollution – recommended using risk coefficients from the American Cancer Society (ACS) study (*13*) to estimate the effects of chronic exposure to PM on life expectancy in Europe. This study is the largest cohort study published in the scientific literature on the association between mortality and exposure to PM in air. The risk estimates from this study were also used in the WHO Global Burden of Disease project (*14*). This project estimated that exposure to fine PM in outdoor air leads to about 100 000 deaths and 725 000 years of life lost each year in Europe.

The risk estimate found in the ACS study is appropriate for estimating effects on health

[2] In a cohort study a (usually) large group of individuals (a cohort) is classified with respect to the presence or absence of a risk factor (e.g. air pollution). The cohort is then followed for some time, and occurrences of events of interest (e.g. mortality) are registered relative to the risk factor.

7. CONSEQUENCES FOR EUROPEAN CLEAN AIR POLICY AND FOLLOW-UP OF THE SYSTEMATIC REVIEW

FURTHER ACTION IS NEEDED!

The findings of the systematic review and the preliminary results of integrated assessment modelling through CAFE on the effects of PM and ozone on mortality clearly demonstrate that further action is needed to reduce levels of these air pollutants in Europe.

HOW SHOULD WE DEFINE NEW AIR QUALITY OBJECTIVES?

Strategies should aim to reduce the overall health burden

As stated previously, the ultimate goal of European clean air policy is to achieve levels of air quality that do not give rise to significant negative effects on or risks to human health and the environment. However, the results of the systematic review confirmed the existence of severe effects of PM and ozone on human health even at concentrations at the lower end of the current ranges. Thus the objective of the Sixth EAP – no significant negative impact of air pollution on human health – seems out of reach in the short and medium term for these pollutants. It therefore seems reasonable to define ambitious though achievable interim targets within CAFE to enhance current efforts to combat air pollution. From a health point of view, such intermediate targets should obviously facilitate a significant and effective reduction of the *overall* health burden from air pollution, and also protect susceptible groups. Since the health benefits are, formally speaking, determined by (*a*) a reduction in pollution levels, (*b*) the concentration–response function and (*c*) the population affected, all these three points have to be considered simultaneously.

WHICH GUIDELINE VALUES?

There is no concrete proposal for a specific guideline value for PM and ozone at this stage

WHO air quality guidelines values have been used previously to directly derive legally binding air quality standards. For example, the guideline values for nitrogen dioxide of 200 μg/m^3 as one-hour mean and of 40 μg/m^3 as annual mean have been translated into EU legislation as limit values. The process of deriving limit values (or other objectives related to air pollution) is often more complex for pollutants for which no apparent no-effect thresholds can be defined based on current evidence. In such cases, a reduction in exposure to levels as low as reasonably achievable would be desirable from the health point of view. Nevertheless, it has to be acknowledged that other considerations must be taken into account, such as current pollution levels, natural background concentrations, attainability, and cost–effectiveness and cost–benefit ratios. The latter points were not covered by the WHO systematic review but are considered under "integrated assessment"[3] as part of the CAFE programme. Therefore, the systematic review did not propose a concrete numerical guideline value for PM or ozone at this stage, but rather provided health-related information such as concentration–response functions for the process of integrated assessment

[3] Integrated assessment is a tool to identify cost-effective emission reduction strategies to achieve certain environmental objectives.

SHOULD WE CARE ABOUT HOT SPOTS?

Current EU legislation requires air quality assessment (and management, if certain pollution levels are exceeded) both in areas where the highest concentrations occur (so-called "hot spots" such as near very busy roads or in the vicinity of industrial installations) to which the population is likely to be exposed and in areas that are representative of the exposure of the general population. The systematic review confirmed the validity of such an approach. A policy that aims at a significant reduction in the overall health burden caused by air pollution will have to aim to reduce the exposure of the general population. This is particularly true for pollutants/health end-points with (*a*) no threshold of effects and (*b*) a linear relationship between exposure and response. Some studies have shown, however, that people living close to busy roads experience more short- and long-term effects of air pollution than those living further away. The public health burden of exposures at hot spots may therefore be significant, and regulatory efforts should also pay attention to those areas. In addition, WHO notes that an unequal distribution of health risks over the population raises concerns of environmental justice and equity.

Focus on urban background and "hot spots"

DO WE NEED ADDITIONAL RESEARCH?

Even though the evidence on the relationship between exposure to different air pollutants and health effects has increased considerably over the past few years, there are still large uncertainties and important gaps in knowledge. These gaps can be reduced only by targeted scientific research. Areas in which such research is urgently needed include exposure assessment, dosimetry, toxicity of different components, biological mechanisms of effects, susceptible groups and individual susceptibility (taking into account gene–environment interactions), effects of mixtures versus single substances, and effects of long-term exposure to air pollution. The systematic review clearly demonstrated the need to set up a more comprehensive monitoring and surveillance programme for air pollution and health in different European cities. Air pollutants to be monitored include coarse PM, $PM_{2.5}$, PM_1, ultrafine particles, chemical composition of PM including elemental and organic carbon, and gases such as ozone, nitrogen dioxide and sulfur dioxide. The value of black smoke and ultrafine particles as indicators of traffic-related air pollution should also be evaluated. Furthermore, periodic surveillance of health effects requires better standardization of routinely collected health outcome data. The systematic review also showed that there needs to be a system for maintaining the literature database and for developing the science of meta-analysis for the purpose of monitoring research findings, summarizing the literature for health effects, and health impact assessment.

The European Community and national institutions are invited to make appropriate funding available to facilitate the corresponding studies, such as through the forthcoming 7th Framework Programme of the European Community for research, technological development and demonstration activities.

IS THERE A NEED TO UPDATE THE WHO AIR QUALITY GUIDELINES?

The WHO air quality guidelines for PM and ozone will be updated

In recent years, a large body of new scientific evidence has emerged that has strengthened the link between ambient PM exposure and health effects (especially cardiovascular effects), justifying reconsideration of the current WHO air quality guidelines for PM and the underlying exposure–response relationships. Since the present information shows that fine particles (commonly measured as $PM_{2.5}$) are strongly associated with mortality and other end-points such as hospitalization for cardiopulmonary disease, it is recommended that air quality guidelines for $PM_{2.5}$ be further developed. Revision of the guidelines for PM_{10} is also indicated. Additional evidence suggests that coarse particles (those between 2.5 and 10 μm) also affect health, and a separate guideline for coarse particles may be warranted. The value of black smoke and ultrafine particles as indicators of traffic-related air pollution should also be re-evaluated.

Recent epidemiological studies have strengthened the evidence that there are short-term effects of ozone on mortality and respiratory morbidity and provide further information on exposure–response relationships and effect modification. There is new epidemiological evidence on long-term ozone effects and experimental evidence on lung damage and inflammatory responses. Thus the systematic review concluded that there is sufficient evidence to reconsider the current WHO air quality guidelines.

Based on these recommendations, WHO has launched the formal process of updating its air quality guidelines. It is planned to involve experts from all WHO regions in this exercise and to publish a revised version of the guidelines in 2005.

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This report summarizes the most recent information on the health effects of air pollution. It is based on the results of a comprehensive review of scientific evidence organized by the World Health Organization in support of air pollution policy development in Europe, and in particular the European Commission's Clean Air for Europe (CAFE) programme. The review indicates that air pollution at current levels still poses a considerable burden on health in Europe. Many different adverse effects have been linked to exposure to air pollution, including an increased risk of cardiopulmonary disease and a reduction in life expectancy of a year or more for people living in European cities. Some of these effects occur at very low concentrations that were previously considered safe. Taken together, the evidence is sufficient to strongly recommend further policy action to reduce levels of air pollutants, including particulates, nitrogen dioxide and ozone. It is reasonable to assume that a reduction in air pollution will lead to considerable health benefits.

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