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AIR QUALITY GUIDELINES
FOR MAJOR URBAN AIR POLLUTANTS

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The WHO Regional Office for Europe, in the process of establishing air quality guidelines for Member States of the European Region, held the Working Group on Air Quality Guidelines for Major Urban Air Pollutants in Bilthoven, the Netherlands, 14-19 October 1985, as the last in a series of meetings dealing with different air pollutants. The Working Group comprised 24 temporary advisers from 12 countries of Europe and North America.

Discussion

Discussions were held in plenary sessions and in four subgroups on the state of knowledge about the effects on health of sulfur dioxide (SO_2) and particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_X) including nitrogen dioxide (NO_2), and ozone (O_3) and photochemical oxidants. Several common issues were considered: susceptible subpopulations, margins of safety, the definition of adverse effects, uncertainties in knowledge of dose-response relationships, mechanisms of action and establishing time averages for the guidelines.

Some subpopulations respond to lower levels of pollutants. When these groups comprise a significant proportion of the population, guidelines have to be set to protect them. A widely accepted definition of an adverse health effect does not exist, since effects range from the detection of a slight odour to death, with multiple gradations of severity in between. Consequently, the Group graded effects into different levels of severity and health risk.

Aware of the limited data and other constraints on knowledge and accepting that the concentration, length and pattern of exposure are the prime determinants of health effects, the Group made judgements on how to relate existing health data to practical experience when recommending time averages for the guidelines.

The Working Group also realized that it had addressed only one major portion of the effects of urban air pollutants, namely direct health effects, and that ecological effects can have a significant indirect influence on health and general wellbeing. For example, most of the pollutants discussed here, sometimes at low levels, are known to have adverse effects on plants, including crops. The Group considered the results of a previous meeting on ecological effects and recognized the importance of taking an integrated view of effects on both health and the environment in air quality management.

Conclusions

Sulfur dioxide and particulate matter

The combustion of fossil fuels is the prime source of SO_2. Within Europe, rural annual mean SO_2 levels range from near 0 ug/m^3 to about 30 ug/m^3. Annual mean levels of SO_2 in the major cities of Europe are largely below 100 ug/m^3. Maximum daily mean values fall mainly in the range of 250-500 ug/m^3 SO_2. Peaks over shorter averaging periods, such as one hour, extend to 1000-2000 ug/m^3 SO_2, and in some situations higher transient peaks may also occur.

A proportion of the SO_2, especially from elevated point sources, is transformed in the atmosphere into sulfuric acid (H_2SO_4), an important component of acid rain. Current average levels of H_2SO_4 in Europe and North America are generally not measured. The highest levels reported in recent years are in the range of 20-30 ug/m^3 H_2SO_4 (six-hour average) in North America and 28 ug/m^3 H_2SO_4 (one-hour average) in Europe; 680 ug/m^3 H_2SO_4 was observed as a one-hour average in 1962 in London.

Whereas SO_2 is a uniform gas, airborne PM is a complex mixture of organic and inorganic substances. The mass and composition of PM tend to separate into two principal size groups: coarse particles (more than 2 um in aerodynamic diameter) and fine particles (less than 2 um in aerodynamic diameter). The smaller particles contain the secondarily formed aerosols (gases converted to particles), combustion particles and recondensed organic and metal vapours. The larger particles usually contain soil materials, such as fugitive dust from roads and industries. In rural areas within Europe, black smoke (BS) values extend up to about 10 ug/m^3. In the larger cities, annual mean concentrations of smoke range from 10 ug/m^3 to 40 ug/m^3; annual values from gravimetric measurements lie between about 50 ug/m^3 and 150 ug/m^3. Corresponding maxima are 100-250 ug/m^3 for BS and 200-400 ug/m^3 for suspended PM, measured gravimetrically. For guidelines, a division into three categories is appropriate: SO_2, acidic aerosols (sulfates), and SO_2 mixed with PM.

$\underline{SO_2}$. Among exercising asthmatic people, an increase in airway resistance, which is of concern for health, is demonstrable down to a concentration of about 1000 ug/m^3 SO_2. Discernible effects of less certain consequence have occurred below this level. Such effects were observed in experiments in which subjects were exposed to SO_2 for 10 minutes and sometimes after even shorter exposure times.

Acidic aerosol (sulfates). Increased airway resistance and decreased forced expiratory volume in one second have been reported in one study at a concentration of 350 ug/m^3 H_2SO_4 and in another study of asthmatic adolescents undergoing exercise at 100 ug/m^3 H_2SO_4 for 10 minutes. Reversible changes in the baseline rate of bronchial mucociliary clearance in healthy nonsmoking adults at rest occur at exposure to a concentration of 100 ug/m^3 H_2SO_4 for one hour.

Reliable human data concerning the lowest observed chronic effect level are not available. Limited animal data indicate that 100 ug/m^3, one hour per day, five days a week, for six months can cause a persistent shift in baseline bronchial mucociliary clearance. It is extremely difficult to estimate a no-effect level for population exposure to H_2SO_4 or other acid aerosols based on available evidence. However, cross-sectional analysis of variations in mortality among standard metropolitan areas in the United States indicated that, among available pollutant indices, sulfate measurement was the best predictor of mortality (annual average concentration below 15 ug/m^3 sulfate). Sulfate concentrations may be regarded as a surrogate for H_2SO_4 content in these studies, and the observations therefore indicate the potential importance of acid aerosols for health.

- SO_2 and PM. Variations in 24-hour average concentrations of SO_2, BS and total suspended particulates (TSP) have been associated with increased mortality, morbidity and deficits in pulmonary function in epidemiological studies. The lowest exposure levels related to health effects found in epidemiological studies are summarized in Table 1.

It remains uncertain as to which components of the SO_2/PM complex are involved in the adverse effects, though increasing attention is being given to the role of secondary products such as acid sulfates. Measurements of BS can no longer be interpreted in terms of ug/m^3 in many localities, although the BS measurement method is still a valuable index of soiling capacity and of the type of coal smoke pollution that has been associated in the past with adverse health effects. To provide continuity for any further epidemiological studies, BS observations should be continued. The size range of particles sampled by the TSP measurement method includes

Table 1. Summary of lowest observed effect levels (in ug/m^3) of SO_2/PM on health

SO_2	BS	TSP	TP	Effects
Short-term exposure (24-hour mean)				
500	500			Excess mortality
250	250			Increased acute respiratory morbidity (adults)
		180	110	Decrements in lung function (children)
Long-term exposure (annual mean)				
100	100			Increased respiratory symptoms or illness
		180		Decrements in lung function

particles bigger than those able to penetrate the upper respiratory tract. Gravimetric measurements representing the size range of particles inhaled into the thorax (below 10 um) have therefore been specified as thoracic particles (TP) by the International Organization for Standardization (ISO). Efforts should be made to establish such measurements. Trying to specify actual guidelines now, in terms of TSP, would be misleading. TSP measurements, however, may be used for comparative studies with newer indices of pollution and may be a valuable supplement to gravimetric TP measurements.

Carbon monoxide

The largest anthropogenic sources of outdoor levels of CO are emissions from motor vehicles, industrial processes, heating facilities and incinerators. The main indoor sources are unvented combustion appliances and tobacco smoking. Natural background levels of CO vary between 0.01 mg/m^3 and 0.23 mg/m^3. Eight-hour mean concentrations are generally less than 20 mg/m^3. Maximum eight-hour mean concentrations up to 60 mg/m^3, however, have occasionally been recorded. In kitchens, short-term concentrations of 11.5-34.5 mg/m^3 CO have been found, occasionally reaching 57.5 mg/m^3 or more.

Lack of oxygen caused by inhaling CO leads to deficient function in sensitive organs and tissues such as the brain, heart, the inner walls of blood vessels, and platelets. At higher levels of carboxyhaemoglobin (COHb), hypoxia may lead to secondary effects, including a decrease in pH and changes in fibrinolysis. Perinatal effects such as low birth weight and slow postnatal development have also been described. There is general agreement that, from levels of 10-15% COHb upwards, many of these malfunctions may occur, as well as subjective symptoms such as headache or dizziness. Average COHb levels are around 1.2-1.5% for the general population and around 3-4% in cigarette smokers. Heavy smokers may reach levels of about 10% COHb.

For low COHb levels (below 10%), mainly cardiovascular and neurobehavioural effects have to be evaluated. The aggravation of symptoms in angina patients, which occurs at COHb levels of 2.9-4.5%, is an adverse health effect of great concern. Among healthy young adults, a decreased oxygen uptake capacity and a resultant decreased work capacity under maximal exercise conditions have been clearly shown, starting at a level of 5.0% COHb. However, some studies observed small but significant decreases in work time, due to exhaustion, at

COHb levels in the range of 2.3–4.3%, although maximum aerobic capacity was not diminished. From the empirical evidence on neurobehavioural effects, COHb levels around 5% produce decrements in neurobehavioural function. Transient cardiovascular and neurobehavioural effects have been reported in the range of 2–3% COHb, but these findings could not be reproduced by other authors and the methods used in these studies have been severely criticized.

Nitrogen oxides

Various forms of NO_x exist, but the most relevant for health is NO_2. NO_2 is typically formed by oxidation of NO emitted from mobile and stationary sources, although some sources emit NO_2 directly. Unvented gas combustion appliances and cigarette smoking are major sources of indoor levels of NO_x. Levels of NO_2 vary widely, since a continuous baseline level of NO_2 is often present, on which peaks of higher levels are superimposed. Natural background levels range from 0.4 ug/m^3 to 9.4 ug/m^3. Outdoor urban levels have an annual mean ranging from 20 ug/m^3 to 90 ug/m^3 and a one-hour mean ranging from 240 ug/m^3 to 850 ug/m^3. Indoor levels with unvented gas combustion appliances may average over 200 ug/m^3 over a period of several days. A maximum one-hour peak may reach 2000 ug/m^3.

Normal people exposed at rest or during light exercise for less than two hours to concentrations above 4700 ug/m^3 NO_2 experience pronounced decrements in pulmonary function. A wide range of findings have been reported; one study observed no effect due to a 1.25-hour exposure to 7520 ug/m^3, while another showed an increase in airway resistance after a 20-minute exposure to 500 ug/m^3. Asthmatics are likely to be the most sensitive subjects, although uncertainties in the health data base exist. The lowest reported effects on pulmonary function are from two laboratories that exposed mild asthmatics for 30 minutes to 560 ug/m^3 NO_2 during intermittent exercise. One of these studies also indicates that NO_2 can increase airway reactivity to cold air in asthmatics. In most experiments conducted at a concentration of 188 ug/m^3 NO_2 for one hour, the pulmonary function of asthmatics was not significantly changed.

NO_2 increases bronchial reactivity, as measured by pharmacological bronchoconstrictors, in normal and asthmatic subjects even at levels that do not affect pulmonary function directly in the absence of a bronchoconstrictor. Since actual mechanisms are not fully defined and NO_2 studies with allergen challenges showed no effects at the lowest level tested (190 ug/m^3), an accurate evaluation of the risk to health of the increased responsiveness to bronchoconstrictors is not yet possible.

Studies with animals rarely indicate the effects of acute exposure to less than 1880 ug/m^3 NO_2. Several weeks or months of exposure to less than 1880 ug/m^3 NO_2, however, cause a plethora of effects, primarily in the lung but also in other organs. Structural changes range from a change in cell types in the tracheobronchial and pulmonary regions (lowest reported level 640 ug/m^3) to effects similar to emphysema (lowest reported level 190 ug/m^3, with peaks of 1880 ug/m^3). Biochemical changes often reflect the cellular alterations (lowest reported level 380–750 ug/m^3). Levels of NO_2 as low as 940 ug/m^3 also increase susceptibility of the lungs to bacterial infection.

No epidemiological studies related to outdoor exposure can be used to evaluate quantitatively the risk of exposure to NO_2. Homes with gas cooking appliances have peak levels of NO_2 in the same range as levels that cause effects in animal and human clinical studies.

Many of the epidemiological studies of adults and children have shown no significant effect of the use of gas cooking appliances on either respiratory symptoms or lung function. Nevertheless, a few studies have shown significant relationships in various subgroups so that the precise relationship between health and gas cooking (and by implication, NO_2) remains unclear.

Ozone and other photochemical oxidants

O_3 and other photochemical oxidants are formed through the action of sunlight on NO_2 and olefines. Natural background levels of O_3 are usually less than 30 ug/m^3, but can be as much as 120 ug/m^3 for one hour. Maximum hourly O_3 concentrations may exceed 200 ug/m^3 in rural areas and 300 ug/m^3 in urban areas of Europe. The highest 30-minute value recorded in the Federal Republic of Germany is 664 ug/m^3. Submaximal levels can occur 8-10 hours a day for many consecutive days.

O_3 toxicity occurs in a continuum in which higher concentrations cause greater effects. Several studies suggest that there is no threshold for an observed effect of O_3. Short-term acute effects that have been noticed begin with the annoyance effect of eye irritation. These effects occur because of the presence of non-O_3 oxidants at 200 ug/m^3 O_3 or perhaps lower levels. Symptomatic effects on the chest and upper respiratory tract occur at higher levels, particularly in susceptible populations. Substantial acute adverse effects will definitely occur in people exposed to 1000 ug/m^3 O_3 for one hour.

Epidemiological field studies with children have indicated that pulmonary function decrements can occur at concentrations of 220 ug/m^3 O_3 or less. Other studies have associated changes in pulmonary function in children or asthmatics with exposure to 160-340 ug/m^3 O_3, but there were also associations with changes in temperature or other pollutants. Various symptoms, including cough and headache, have been associated with concentrations as low as 160-300 ug/m^3 O_3.

The exposure of heavily exercising adults or children resulted in decrements in pulmonary function due to a 2.5-hour exposure to 240 ug/m^3 O_3. Higher concentrations are required to elicit pulmonary effects when exposure time is shorter or when the level of exercise is decreased. The inhalation of O_3 with and without other ambient oxidants demonstrates that the functional and symptomatic responses at low levels of O_3 are primarily due to O_3 alone.

A number of studies evaluating animals exposed to O_3 for a few hours or days have shown alterations in lung biochemistry or other endpoints in which the lowest observed effect levels are in the range of 160-400 ug/m^3. These include the potentiation of bacterial lung infections, increased mitochondrial oxygen consumption in vitamin E deficient and normal rats, morphological alterations in the lung, and increases in the activity of certain lung enzymes active in oxidant defences. Suggestions of changes in pulmonary functions in animals following long-term exposure to levels of O_3 in the range of 240-400 ug/m^3 have also been reported.

Recommendations

Sulfur dioxide and particulate matter

1. For SO_2, it appears reasonable to apply a margin of safety of 2 for the protection of public health; a concentration of 500 ug/m^3 over 10 minutes should not be exceeded. One-hour maximum values that achieve this guideline can be calculated as approximately 350 ug/m^3.

2. Recommendations for limits of concentrations and for averaging times for the strong acid content of ambient aerosol cannot now be made owing to the sparsity of current data on effects and ambient exposure levels. However, monitoring is warranted when levels exceed 10 ug/m^3 (determined as H_2SO_4 or equivalent acidity of aerosol). Therefore, ambient air shold be regularly monitored for H^+-ion concentration of the aerosol (which should be sampled in a size fractionating particulate sampler) when levels of this magnitude are likely to occur.

3. In proposing guidelines (Table 2) based on present knowledge for exposure to both SO_2 and PM, an arbitrary safety factor of 2 has been used in relation to the morbidity and mortality data and a factor of 1.5 has been used for the decrement in lung function, which is considered to be a less severe effect.

Carbon monoxide

1. As smoking is a major contributor to the carboxyhaemoglobin (COHb) levels of smokers, recommendations for exposure limits are designed to protect nonsmokers. A level of 2.5-3% is recommended for the protection of the general population, including sensitive groups.

2. Formulae may be used to estimate the COHb level related to the duration of exposure to a certain concentration in ambient air. Guideline values for exposure conditions to prevent COHb levels exceeding 2.5-3% in nonsmoking populations are proposed. The maximum permitted exposure should be 115 mg/m^3 for periods not exceeding 15 minutes, and time-weighted average exposures of the following levels for the indicated periods of exposure should not to be exceeded: 55 mg/m^3 for 30 minutes; 29 mg/m^3 for one hour; 11.5 mg/m^3 for 8-24 hours.

Table 2. Guideline values (ug/m³) for SO_2, BS and gravimetrically determined particulates consistent with the protection of public health

	SO_2	BS[a]	TSP[b]	TP[c]
24-hour mean	125	125	120	70
Annual mean	50	50	-[d]	-

[a] Application of BS values is recommended only in areas where coal smoke from domestic fires is the dominant component of the particulates.

[b] TSP measured by high volume sampler. Values for gravimetrically determined particulates are to be regarded as tentative at this stage, being based on a single published study.

[c] TP values as specified by ISO are estimated from TSP (same study as mentioned under footnote [b]) using site-specific TSP/TP ratio. Value to be regarded as tentative.

[d] Data on long-term effects related to annual means were considered to be inadequate at this stage for the evaluation of guidelines.

Nitrogen oxides

1. A one-hour guideline value of 400 ug/m³ NO_2 should not be exceeded, based on the judgement that the minimal observed effect level in asthmatics (560 ug/m³) is not necessarily adverse and a guideline somewhat lower provides a further margin of safety.

2. A 24-hour guideline value of 150 ug/m^3 NO_2 should not be exceeded, based on the judgement that repeated exposures approaching the minimal repeatedly observed effect level are to be avoided to create a margin of safety from chronic effects.

Ozone and other photochemical oxidants

1. Existing data about the health effects of O_3, as well as its natural high background level, lead to the recommendation of a one-hour guideline value in the range of 150-200 ug/m^3 O_3.

2. To lessen the potential for adverse acute and chronic effects and to provide an additional margin of safety, consideration should be given to an eight-hour guideline value for exposure of 100-120 ug/m^3 O_3.

3. The recommendation of a guideline for peroxyacylnitrates is not warranted at this time, since they do not seem to create a significant health problem at existing ambient levels.

Annex 1

WORKING PAPERS[a]

ICP/CEH 002/m69/7	Working paper on SO_2 and particulate matter, by Professor G.F. Nordberg
ICP/CEH 002/m69/8	Working paper on carbon monoxide, by Professor M. Haider
ICP/CEH 002/m69/9	Working paper on O_3/photochemical oxidants, by Dr P.J.A. Rombout, Dr M. Mara and Dr T.S. Veninga
ICP/CEH 002/m69/10	Working paper on nitrogen oxides, by Professor G. von Nieding

[a] Copies available from the Air Quality Guidelines unit, WHO Regional Office for Europe, 8 Scherfigsvej, DK-2100 Copenhagen Ø, Denmark.

Annex 2

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