WHO AIR QUALITY GUIDELINES GLOBAL UPDATE 2005

MEETING REPORT

WHOLIS number
E87950
Original: English

World Health Organization

WHO air quality guidelines global update 2005

**Report on a working group meeting,
Bonn, Germany, 18--20 October 2005**

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ABSTRACT

To update the WHO Air quality guidelines (AQG), and to assure their global applicability, WHO established a working group consisting of experts in epidemiology, toxicology, air quality exposure assessment, air quality management, and public policy. Based on the review of the newly accumulated evidence on health aspects of air pollution, the working group agreed on the updated guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. To facilitate implementation of the guidelines in all WHO Regions, especially in more polluted areas, the group recommended interim targets which, if achieved, would result in significant reductions in pollutant-related health risks and would indicate a progress towards the guideline values.

Keywords

AIR POLLUTION – prevention and control
AIR POLLUTANTS
GUIDELINES

EUR/05/5046029

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Introduction

The WHO Air quality guidelines (AQG) are designed to offer guidance in reducing the health impacts of air pollution based on expert evaluation of current scientific evidence. Since the most recent update of the WHO AQG, completed in 1997 and printed as a WHO publication in 2000 (WHO 2000), there has been an increasing awareness among scientists and policy makers of the global nature of the public health problems posed by exposure to air pollution. Hundreds of new studies have been published on the health effects of air pollution in the scientific literature, including important new research in low-and middle-income countries where air pollution levels are the highest. An assessment organized by WHO of the global and regional burden of disease due to air pollution, focused attention on the geographic distribution of the problem and its scale: more than 2 million premature deaths each year are attributed to urban outdoor air pollution and indoor air pollution from the burning of solid fuels, and more than half of this burden is borne by the populations of developing countries (World Health Report, 2002). WHO then initiated a global consultation on the conclusions emerging from the accumulated scientific evidence and its use for the update of the WHO AQG. The updated WHO AQG are intended to be relevant to the highly diverse emissions, human exposure and exposure-related disease that apply across WHO's regions, and to support a broad range of policy options for air quality management in various parts of the world.

Scope of the update

WHO established a steering group to advise and guide the guideline development process[1]. The steering group agreed on the scope and methodology of the update, and identified experts to contribute to the review of the scientific literature. The updated guidelines consist of two parts. Part 1 comprises background materials, which provide a brief yet comprehensive review of the issues affecting the application of the WHO AQG in risk assessment and policy development. Part 2 reviews the health hazards of particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2), and based on those reviews, formulates health-based guidelines for each pollutant (see Annex 1). The scope of the updated guidelines reflects the steering group's judgement concerning both the availability of new evidence on the health effects of specific pollutants and the relative importance of the specific pollutants with regard to current and future health effects of air pollution in each of the WHO Regions. That additional pollutants, such as carbon monoxide, were not included in the present

[1] Steering Group members: RH Anderson (UK), B. Brunekreef (The Netherlands), B. Chen (China), A. Cohen (USA), R. Maynard (UK), I. Romieu (Mexico), KR. Smith (USA), S. Wangwongwatana (Thailand)

review reflects the limited resources available to the project. As a result, the 2000 WHO AQGs for pollutants not considered in the current update remain in effect. The Steering Group (SG) recommends that the update of the guidelines be expanded to include additional pollutants as soon as possible when resources become available.

Process

The SG recommended to WHO, experts in epidemiology, toxicology, air quality exposure assessment, air quality management, and public policy to draft Parts 1 and 2 of the guideline document. After initial review and approval by the SG, initial drafts were distributed for external review to a wide group of experts in all the relevant disciplines. WHO also sought the opinions of air quality managers and policy makers concerning the rationale and format of the guidelines, seeking to improve their applicability in various parts of the world. An effort was made to ensure representation of a wide group of Member States from all WHO regions.

WHO convened the Working Group on Air Quality Guidelines in Bonn, 18-20 October 2005 to finalize the updated WHO AQG. The tasks of the meeting were to formulate the guidelines for the four specific pollutants, and to agree on supporting text. The Working Group (WG) consisted of the authors of the draft chapters, the external reviewers of the drafts, and the members of the steering group (see Annex 2). Dr Robert Maynard chaired the meeting, and Dr Aaron Cohen acted as the meeting rapporteur. The comments on the drafts of Parts 1 and 2, received from the reviewers, were circulated to the steering group members, authors and all reviewers in advance of the meeting. Since not all reviewers participated in the WG meeting, the list of those submitting written comments but not present in the meeting is presented in Annex 3.

In a series of plenary discussions and small drafting group sessions, the WG reviewed the general approach to the guidelines' formulation, discussed outstanding comments of the reviewers and agreed on the general contents of the background material. The drafting groups discussed in detail the formulation of the updated guidelines and the text supporting them. The final decisions concerning the guidelines were made in plenary by consensus. This report presents the updated guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide agreed by the working group, and summarizes the WG's discussions. It includes the corrections received from the WG members resulting from their review of the first version of the report distributed after the meeting. The WG is preparing the full text of parts 1 and 2 for publication according to a schedule of follow-up actions, agreed at the meeting. The target date for the publication of the full material is set for late summer 2006.

Funding

The current update of the WHO AQG has been supported financially by the Protection of Human Environment programme at WHO headquarters as well as the WHO European Centre for Environment and Health, (Bonn Office) funds donated by the German Ministry of the Environment, the Department of Health, United Kingdom, and the Federal Agency for the Environment, Forests and Landscapes, Switzerland, as well as the Ministry of the Environment, the Netherlands. The contribution of the Pan American Health Organization to the travel costs of experts from Latin America is also acknowledged.

Summary of the discussion

Application of air quality guidelines for policy development and risk reduction

A substantial part of the plenary discussion focused on the use of the guidelines in air quality management and its implications for their format and interpretation. For some key pollutants, such as particulate matter (PM), the review conducted for the second edition of the WHO AQGs (WHO 2000) noted that there was growing evidence of adverse health effects at low levels of exposure, and that researchers had been unable to identify a clear threshold, or level below which there were no adverse effects. This was viewed as problematic, given that the prevailing notion of an AQG value assumed a "concentration(s) of chemical compounds in the air that would not pose adverse effects of health." Therefore, the second edition of WHO AQGs declined to set a guideline value for PM, and instead offered guidance for risk managers in the form of a statistical model relating exposure to risk, suggesting that they quantify the risk at locally relevant exposure levels, and use those local estimates to guide policy making. This approach to no threshold pollutants has been applied widely in risk management of environmental chemicals (e.g. in risk assessment of genotoxic carcinogens).

Although WHO has not evaluated formally how the current guidelines have been used in air quality management, it was the view of working group members from developing countries that the approach taken for PM in the 2000 WHO AQGs had not been well accepted by air quality managers and policy makers. Therefore many WG members recommended that the updated guidelines define concentrations for the considered pollutants, which if achieved, would be expected to result in significantly reduced rates of adverse health effects. These concentrations should be based on the available scientific evidence and would provide an explicit objective for air quality managers and policy makers to consider when setting the national air quality standards and management strategies. Given that air pollution levels in

developing countries often far exceed the recommended WHO AQGs, the WG also proposed interim target (IT) levels, in excess of the WHO AQGs themselves, to promote steady progress towards meeting the WHO AQGs.

The WG considered that specifying a single pollutant concentration as the WHO AQG in a "no-threshold" context could be viewed as implying an "acceptable" level of adverse health effects in the population. It noted, however, that in all situations there would always be some sensitive individuals who are adversely affected when exposed to levels below the WHO AQG. Some members noted that the specification of IT values were an implicit acknowledgement of a continuously increasing relative risk of exposure. Ultimately, the majority of the WG agreed that specifying explicit guideline levels and interim targets as described above would be most useful for air quality management and public health protection worldwide, especially in regions that currently bear the largest burden of disease due to air pollution. The WG emphasized the need to reduce exposure to non-threshold pollutants even where current concentrations are close to or below the proposed guidelines.

The WG's deliberations focused largely on exposures to and health effects of pollutants from outdoor sources. It was acknowledged, however, that in the case of PM the highest exposures and greatest estimated burden of disease were in developing countries and were due to indoor combustion of solid fuels, and that other pollutants emitted indoors, such as NO_2, may also pose significant hazards. The WG concluded that the guidelines should be interpreted as applying in all microenvironments where population exposure occurred, both outdoors and indoors. The importance of indoor exposure to air pollution is discussed in part 1 of the guideline document, focusing on health burden from air pollution due to indoor combustion of solid fuels. However, management of air quality in homes, including the design of more targeted guidelines, may require different approaches than those applicable to outdoor exposure. The WG and SG advised WHO to include this topic in its follow up activities.

Occupational settings are excluded from consideration of these guidelines, as these usually apply to adult working populations, which may differ in susceptibility to pollutants in a number of ways from the general population, and where the risk management approaches may be different than those applicable for ambient air.

Comments on chapters in part 1.

As noted above, Part 1 comprises background materials that provide a brief yet comprehensive review of the issues affecting the application of the WHO AQG in risk assessment and policy development. The WG emphasized the need for appropriate balance in presenting

globally relevant issues as well as regionally specific concerns. The authors preparing the second draft of the chapters in part 1 will use the specific comments emerging from the discussion on each chapter, together with the comments obtained in writing from the reviewers.

Updated air quality guidelines

After agreeing on the general scope and coverage of the chapters reviewing the evidence on health effects of particulate matter, ozone, nitrogen dioxide and sulfur dioxide, four drafting groups discussed in detail the formulation of the guidelines for individual pollutants.

Introductory comments

These guidelines are written for worldwide use, intended to support actions aiming for air quality at the optimal achievable level of public health protection in different contexts. Air quality standards are an important instrument of risk management and environmental policies, and should be set by each country to protect the public health of their citizens. The standards set in each country will vary according to country-specific approaches toward balancing risks to health, technological feasibility, economic considerations, and other political and social factors. This variability will depend on the country's level of development, capability in air quality management and other factors. The guidelines recommended by this WG and presented below, acknowledge this heterogeneity and, in particular, recognize that when formulating policy targets, governments should consider their own local circumstances carefully before using the guidelines directly as legally based standards.

The WG did not provide updated guidance on how statistical models relating exposure and risk could be used to inform air quality management and standard setting. In part, this was due to perceived difficulties in applying the available scientific evidence from epidemiological studies in developed countries, to estimate impacts in developing countries. However, where comparisons have been made, risk coefficients in underdeveloped countries have been found to be similar to those in developed countries. For policy making, it is reasonable to assume transferability of risk models.

The WHO AQG are based on the extensive scientific evidence on air pollution and its health consequences. Although this information has gaps and uncertainties, it offers a strong foundation for the guidelines. Several overall findings of the research need emphasis in regard to the guidelines.

First, the evidence for ozone and particulate matter shows risks to health at concentrations currently found in many cities of developed

countries; these epidemiological findings imply that guidelines cannot provide full protection, as thresholds below which adverse effects do not occur have not been identified.

Second, an increasing range of adverse effects has been linked to air pollution, especially to airborne particulate matter, at ever-lower concentrations. Guidelines could be based on the most critical population health indicators, such as mortality and unscheduled hospitalizations, or upon more subtle but sensitive indicators, such as physiological measures.

Third, the complexity of the air pollution mixture has been better characterized, making more clear the limitations of controlling air pollution through guidelines for single pollutants. Nitrogen dioxide, for example, is a product of combustion processes and is generally found in the atmosphere in close association with other primary pollutants including ultrafine particles. It is also a precursor of ozone and therefore co-exists in photochemically generated oxidant pollution. Nitrogen dioxide is itself toxic, and its concentrations are often strongly correlated with those of other toxic pollutants. As it is easier to measure, it is often used as a surrogate for the mixture as a whole. Achieving the guidelines for individual pollutants such as nitrogen dioxide may therefore bring benefits for public health that exceed those anticipated based on estimates of the pollutant's specific toxicity.

The present revision of the WHO AQG provides updated guideline values for three of the four pollutants examined. For two of them (particulate matter and ozone), the quantitative relationship between monitored concentration and specific risks to health can be estimated. These estimates provide an input for health impact assessments and allow insights into the mortality and morbidity burdens at current levels of air pollution and at levels that would be achieved under various pollution reduction scenarios. The burden estimates could also be used for the purpose of cost-benefit analysis. Approaches to, and the limitations of, of health impact assessments are summarized in part 1 of the updated guidelines.

For the purpose of this document, ‘annual average’ refers to the arithmetic mean of concentrations, which will typically be measured or reported for each day of the year. Also, the concentration values given refer to monitoring sites representative of population exposures; levels may be higher close to specific sources such as roadways, power plants and large stationary sources, and protection of populations living in such situations may require special measures to bring the pollution levels below the guideline values.

The following sections of this report present:

- **Guideline values for PM, ozone, NO_2, and SO_2.** As noted above, the epidemiological evidence indicates that the possibility of adverse effects remains, even if the guideline value is achieved, and some countries might select even lower concentrations for their standards
- **Interim targets for each pollutant**. As discussed above, these are intended as incremental steps in a progressive reduction of air pollution in more polluted areas and are intended to promote a shift from concentrations with acute, serious health consequences to concentrations that, if achieved, would result in significant reductions in risks for acute and chronic effects. Such progress towards the guideline values should be the objective of air quality management and health risk reduction in all areas.

Particulate matter

The evidence on airborne PM and public health is consistent in showing adverse health effects at exposures experienced by urban populations in cities throughout the world, in both developed and developing countries. The range of effects is broad, affecting the respiratory and cardiovascular systems and extending to children and adults and to a number of large, susceptible groups within the general population. The risk for various outcomes has been shown to increase with exposure and there is little evidence to suggest a threshold below which no adverse health effects would be anticipated. In fact, the lower range of concentrations at which adverse health effects has been demonstrated is not greatly above the background concentration which has been estimated at 3-5 $\mu g/m^3$ in the United States and western Europe for particles smaller than 2.5 micrometer, PM2.5. The epidemiological evidence shows adverse effects of particles after both short-term and long-term exposures.

Current scientific evidence indicates that guidelines cannot be proposed that will lead to complete protection against adverse health effects of particulate matter, as thresholds have not been identified. Rather, the standard-setting process needs to achieve the lowest concentrations possible in the context of local constraints, capabilities, and public health priorities. Quantitative risk assessment offers one approach for comparing alternative scenarios of control and estimating the residual risk with achieving any particular guideline value. The United States Environmental Protection Agency and the European Commission have recently used this approach in making recommendations for revisions of the existing standards for particulate matter. Countries are encouraged to consider an increasingly stringent set of standards, tracking progress through emission reductions and declining concentrations of particulate matter. The numerical guideline values given in the tables provide guidance on the

concentrations at which increasing, and specified mortality responses due to PM are expected based on current scientific insights. As mentioned, to the extent that health effects associated with ambient PM have been reported at relatively low ambient concentrations, and that there is substantial inter-individual variability in exposure and response in a given exposure, it is unlikely that any PM standard or guideline level will provide universal protection for every individual against all possible PM-related effects.

The choice of indicator for particulate matter also merits consideration. The most recent and extensive epidemiological evidence is largely based on studies using PM_{10} as the exposure indicator. Further, at present the majority of monitoring data is based on measurement of PM_{10} as opposed to other particulate matter metrics. As an indicator, PM_{10} comprises the particle mass that enters the respiratory tract and includes both the coarse (PM10-PM2.5) and fine (PM2.5) particles considered to contribute to the health effects observed in urban environments. In most urban environments, both coarse and fine mode particles are likely to be prominent, the former primarily produced by mechanical processes such as construction activities, road dust resuspension and wind, and the latter primarily from combustion sources. The composition of particles in these two size ranges is likely to vary substantially across cities around the world depending upon local geography, meteorology and specific sources. Combustion of wood and other biomass can be a major contributing source to outdoor air pollution as well; the resulting combustion particles are largely in the fine ($PM_{2.5}$) mode. Although few epidemiological studies exist comparing the relative toxicity of combustion from fossil fuel versus biomass, similar effect estimates have been reported over a wide range of cities in both developed and developing countries. Therefore, it is reasonable to assume generally similar effects of $PM_{2.5}$ from these different sources. In the developing world, large populations are exposed to high levels of combustion particles indoors, and the WHO AQG for PM also applies to these situations.

PM_{10} is suggested as an indicator with relevance to the majority of the epidemiological data and for which there is more extensive measurement data throughout the world. However, as discussed below, the **numerical** guideline value itself is based on studies using $PM_{2.5}$ as an indicator and a $PM_{2.5}/PM_{10}$ ratio of 0.5 is used to derive an appropriate PM_{10} guideline value. This ratio of 0.5 is close to that observed typically in developing country urban areas and at the bottom of the range (0.5 – 0.8) found in developed country urban areas. If justified by local conditions, this ratio may be changed based on the local data when the local standards are set.

Based on known health effects, both short-term (24-hour) and long-term (annual) guidelines are needed for both of the PM indicators.

Tables 1 and 2 provide a range of values of which the lowest is designated as the WHO Air quality guideline. The WHO AQGs themselves are

$PM_{2.5}$: 10 μg/m^3 annual mean, 25 μg/m^3 24-hour mean

PM_{10}: 20 μg/m^3 annual mean, 50 μg/m^3 24-hour mean

The annual average guideline value of 10 μg/m^3 for PM2.5 was chosen to represent the lower end of the range over which significant effects on survival have been observed in the American Cancer Society Study (ACS) (Pope et al., 2002). Adoption of a guideline at this level places significant weight on the long-term exposure studies using the ACS and Harvard Six-Cities data (Dockery et al., 1993; Pope et al., 1995; Krewski et al., 2000, Pope 2002, Jarrett 2005). In these studies, robust associations were reported between long-term exposure to PM2.5 and mortality. The historical mean PM2.5 concentration was 18 μg/m^3 (range of 11.0 to 29.6 μg/m^3) in the Six-Cities study and 20 μg/m^3 (range of 9.0 to 33.5 μg/m^3) in the ACS study. Thresholds were not apparent in either of these studies, although the precise period(s) and pattern(s) of relevant exposure could not be ascertained. In the ACS study, statistical uncertainty in the risk estimates becomes apparent at concentrations of about 13 μg/m^3, below which the confidence bounds significantly widen since the concentrations are relatively far from the mean. In the Dockery et al. study, the risks are similar in the cities at the lowest long-term PM2.5 concentrations of 11 and 12.5 μg/m^3. Increases in risk are apparent in the city with the next-lowest long-term PM2.5 mean of 14.9 μg/m^3, indicating likely effects in the range of 11 to 15 μg/m^3. Therefore, an annual concentration of 10 μg/m^3 would be below the mean of the most likely effects levels indicated in the available literature. Targeting a long-term mean PM2.5 concentration of 10 μg/m^3 would also place some weight on the results of daily exposure time-series studies examining relationships between PM2.5 and acute adverse health outcomes. These studies have long-term (three- to four-year) means in the range of 13 to 18 μg/m^3. Although adverse effects on health cannot be entirely ruled out even below that level, the annual average WHO AQG represent levels that have been shown to be achievable in large urban areas in highly developed countries, and attainment is expected to effectively reduce the health risks.

Besides the guideline values, three interim targets (IT) were defined, which have been shown to be achievable with successive and sustained abatement measures. Countries may find these interim targets helpful in gauging progress over time in the difficult process of steadily reducing population exposures to PM.

As the IT-1 level a mean PM2.5 concentration of 35 μg/m^3 was selected. This level is associated with the highest observed values in the studies on long-term health effects and may also reflect higher but unknown historical concentrations that may be responsible for observed health effects. This level has been shown to be associated with significant mortality in the developed world.

The IT-2 interim level of protection is 25μg/m^3 and places greater emphasis on the studies of long-term exposure associated with mortality. This value is above the mean value observed in these studies at which health effects have been observed, and is likely to be associated with significant impacts from both long-term and daily exposures to PM2.5. Attainment of this IT-2 value would reduce risks of long-term exposure by about 6% (95%CI: 2 – 11%) relative to the IT-1 value. The IT-3 level is 15 μg/m^3 and places even greater weight on the likelihood of significant effects related to long-term exposure. This value is close to the mean concentrations observed in studies of long-term exposure and provides an additional 6% reduction in mortality risk relative to IT-2.

Table 1. Air quality guideline and interim targets for particulate matter: annual mean

Annual mean level	**PM_{10} (μg/m^3)**	**$PM_{2.5}$ (μg/m^3)**	**Basis for the selected level**
WHO interim target-1 (IT-1)	70	35	These levels are estimated to be associated with about 15% higher long-term mortality than at AQG
WHO interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower risk of premature mortality by approximately 6% [2-11%] compared to WHO-IT1
WHO interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce mortality risk by another approximately 6% [2-11%] compared to WHO-IT2 levels.
WHO Air quality guidelines (AQG)	**20**	**10**	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to $PM_{2.5}$ in the ACS study (Pope et al., 2002). The use of $PM_{2.5}$ guideline is preferred.

In addition to WHO AQGs and interim targets for $PM_{2.5}$, WHO recommends AQGs and interim targets for PM_{10}. This is because coarse PM (the fraction between 10 and 2.5 μm) cannot be considered harmless, and having a PM2.5 guideline alone would provide no

protection against harmful effects of coarse PM. At the same time, the quantitative evidence on coarse PM is considered insufficient to provide separate guidelines. In contrast, there is a large literature on short-term effects of PM10, which has been used as a basis for the development of the WHO AQGs and interim targets (Table 1).

The 24-hour average values refer to the 99th percentile of the distribution of daily values - that is the 4th next highest value of the year. The frequency distribution of daily PM2.5 or PM10 values is most often roughly log-normal. Depending on the specific characteristics of their sources and location, countries may find that either the 24-hour guidelines or ITs given in this document, or the annual average values are more restrictive. When evaluating the WHO AQG and interim targets, the annual average is suggested to take precedence over the 24-hour average since, at low levels, there is less concern about remaining episodic excursions. Meeting the guideline values for 24 hour mean should protect against peaks of pollution that would lead to substantial excess morbidity or mortality. It is recommended that countries with areas not meeting these guideline values undertake immediate action to achieve these levels in the shortest possible time.

Table 2. Air quality guideline and interim targets for particulate matter: 24-hour mean

24-hour mean level *)	**PM_{10} ($\mu g/m^3$)**	**$PM_{2.5}$ ($\mu g/m^3$)**	**Basis for the selected level**
WHO interim target-1 (IT-1)	150	75	Based on published risk coefficients from multi-centre studies and meta-analyses (about 5% increase of short-term mortality over AQG)
WHO interim target-2 (IT-2)*	100	50	Based on published risk coefficients from multicentre studies and meta-analyses (about 2.5% increase of short-term mortality over AQG)
WHO interim target-3 (IT-3)**	75	37.5	(about 1.2% increase in short-term mortality over AQG)
WHO Air quality guidelines (AQG)	**50**	**25**	Based on relation between 24-hour and annual PM levels

* 99th percentile (3 days/year)

** for management purposes, based on annual average guideline values; precise number to be determined on basis of local frequency distribution of daily means

Multi-city studies of 29 cities in Europe (Katsouyanni et al. 2001)and 20 cities in the United States (Samet et al. 2000) reported short-term mortality effects for PM_{10} of 0.62% and 0.46% per 10 $\mu g/m^3$ respectively. A meta-analysis of 29 cities from outside Western

Europe and North America reported an effect of 0.5% (Cohen et al. 2004). A meta-analysis confined to Asian cities reported an effect of 0.49% (HEI International Oversight Committee 2004). This suggests that the health risks for PM10 are likely to be similar in cities in developed and underdeveloped countries at around 0.5%. Therefore, a concentration of 150 $\mu g/m^3$ would relate to roughly a 5% increase in daily mortality, an impact that would be of significant concern, and one for which immediate mitigation actions would be recommended. The IT-2 level of 100 $\mu g/m^3$ would be associated with approximately a 2.5% increase in daily mortality. The IT-3 level and AQG for the 24-hour average for PM10 are 75 and 50 $\mu g/m^3$, respectively and reflect the relationship between 24-hour and annual average discussed above.

In addition to PM2.5 and PM10, ultra fine particles (UF) have recently attracted significant scientific and medical attention. These are particles smaller than 0.1 micrometer and are measured as number concentration. While there is considerable toxicological evidence of potential detrimental effects of UF particles on human health, the existing body of epidemiological evidence is insufficient to reach a conclusion on the exposure/response relationship to UF particles. Therefore no recommendations can be provided as to guideline concentrations of UF particles at this point.

Ozone

The second edition of the WHO AQG (WHO 2000) set the guideline value for ozone at 120 $\mu g/m^3$ for an 8-hour daily average. Since the mid-1990s there has been no major addition to the evidence from chamber studies or field studies. There has however been a marked increase in health effects evidence from epidemiological time-series studies. Combined evidence from those studies show convincing, though small, positive associations between daily mortality and ozone levels, independent of the effects of particulate matter. Similar associations have been observed in both North America and Europe. These time-series studies have shown effects at ozone concentrations below the previous guideline of 120 $\mu g/m^3$ without clear evidence of a threshold. Evidence from both chamber and field studies also indicate that there is considerable individual variation in response to ozone. In view of these considerations, there is a good case for reducing the WHO AQG from the existing level of 120 $\mu g/m^3$. It is recommended that the air quality guideline for ozone is set at the level of:

ozone: 100 $\mu g/m^3$ for daily maximum 8-hour mean

It is possible that health effects will occur below this level in some sensitive individuals. Based on time-series studies, the number of attributable deaths brought forward can be estimated at 1-2% on days

when ozone concentration reaches this guideline level as compared with the background ozone level.

There is some evidence that ozone also represents unmeasured toxic oxidants arising from similar sources. Measures to control ozone are also likely to control the effects of these pollutants.

Hemispheric background concentrations of tropospheric ozone vary in time and space but can reach average levels of around 80 $\mu g/m^3$. These arise from both anthropogenic and biogenic emissions of ozone precursors and downward intrusion of stratospheric ozone into the troposphere. The proposed guideline value may occasionally be exceeded due to natural causes

There is some evidence that long-term exposure to ozone may have chronic effects but it is not sufficient to recommend an annual guideline.

As concentrations increase above the guideline value, health effects at the population level become increasingly numerous and severe. Such effects can occur in places where concentrations are currently high due to human activities or during episodes of very hot weather.

The 8-hour interim target-1 level has been set at 160 $\mu g/m^3$ at which measurable, though transient, changes in lung function and lung inflammation among healthy young adults have been shown in the presence of intermittent exercise in controlled chamber tests. Although some would argue that these responses may not be adverse, and that they were seen only with vigorous exercise, these views are counterbalanced by the possibility that there are substantial numbers of persons in the general population, including persons of different ages, pre-existing health status, and co-exposures that might be more susceptible than the relatively young and generally healthy subjects who were studied. Furthermore, chamber studies provide little evidence about repeated exposure. The exposure to 160 $\mu g/m^3$ is also likely to be associated with the same effects noted at 100 $\mu g/m^3$. Based on time-series evidence, the number of attributable deaths brought forward can be estimated at 3-5% for daily exposures above the estimated background.

At concentrations exceeding 240 $\mu g/m^3$, important health effects are likely. This is based on findings from a large number of clinical inhalation and field studies. Both healthy adults and asthmatics would experience significant reductions in lung function as well as airway inflammation that would cause symptoms and alter performance. There are additional concerns about increased respiratory morbidity in children. Based on time-series evidence, the number of attributable deaths brought forward can be estimated at 5-9% for daily exposures above the estimated background.

Table 3.Ozone air quality guideline and interim target

	Daily maximum 8-hour mean	**Effects at the selected ozone level**
High level	240 µg/m^3	Significant health effects, substantial proportion of vulnerable population affected.
WHO interim target-1 (IT-1)	160 µg/m^3	Important health effects, an intermediate target for populations with ozone concentrations above this level. Does not provide adequate protection of public health. Rationale: • Lower level of 6.6-hour chamber exposures of healthy exercising young adults, which show physiological and inflammatory lung effects. • Ambient level at various summer camp studies showing effects on health of children. • Estimated 3-5% increase in daily mortality* (based on findings of daily time-series studies)
WHO Air quality guideline (AQG)	**100 µg/m^3**	This concentration will provide adequate protection of public health, though some health effects may occur below this level. Rationale: • Estimated 1-2% increase in daily mortality* (based on findings of daily time-series studies) • Extrapolation from chamber and field studies based on the likelihood that real-life exposure tends to be repetitive and chamber studies do not study highly sensitive or clinically compromised subjects, or children. • Likelihood that ambient ozone is a marker for related oxidants.

* Deaths attributable to ozone concentrations above estimated baseline of 70 µg/m^3. Based on range of 0.3 to 0.5% increase in daily mortality for10µg/m^3 8-hour ozone.

Nitrogen dioxide

Evidence from animal toxicological studies indicates that long-term exposure to NO_2 at concentrations above current ambient concentrations has adverse effects. In population studies NO_2 has been associated with adverse health effects even when the annual average NO_2 concentration complied with the WHO-2000 annual guideline value of 40 µg/m^3. Also some indoor studies suggest effects on respiratory symptoms among infants at concentrations below 40 µg/m^3. Together these results support a lowering of the annual NO_2 guideline value. However, NO_2 is an important constituent of combustion-generated air pollution and is highly correlated with other primary and secondary combustion products, it is unclear to what extent the health effects observed in epidemiological studies are attributable to NO_2 itself or to other correlated pollutants. The current scientific literature, therefore, has

not accumulated sufficient evidence to change the WHO 2000 guideline value of 40 μg/m^3 for annual NO_2 concentration.

Many short term experimental human toxicology studies show acute health effects at levels higher than 500 μg/m^3, and one meta-analysis has indicated effects at levels exceeding 200 μg/m^3. The current scientific literature has not accumulated evidence to change from the WHO 2000 guideline value of 200 μg/m^3 for 1-hour NO_2 concentration.

In conclusion, the guideline values remain unchanged at the following levels**:**

NO_2 concentration: 40 μg/m^3 for annual mean;
NO_2 concentration: 200 μg/m^3 for 1-hour mean.

Rationale

As an air pollutant NO_2 has multiple roles, which are often difficult or sometimes impossible to separate from each other:

(i) Animal and human experimental toxicology indicates that NO_2 is itself - in short-term concentrations exceeding 200 μg/m^3 - a toxic gas with significant health effects.

(ii) Numerous epidemiological studies have used NO_2 as a marker for the air pollution mixture of combustion related pollutants, in particular traffic exhaust or indoor combustion sources. In these studies the observed health effects might also have been associated with other combustion products, e.g. ultrafine particles, NO, particulate matter or benzene. Other studies – both outdoors and indoors - have attempted to focus on the health risks of NO_2, yet the contributing effects of other, highly correlated co-pollutants were often difficult to rule out.

(iii) Most atmospheric NO_2 is emitted as NO, which is rapidly oxidized by O_3 to NO_2. NO_2, in the presence of hydrocarbons and ultraviolet light, is the main source of tropospheric ozone and of nitrate, which forms an important fraction of the ambient air PM2.5 mass.

The present guideline was set to protect the public from health effects of the gas NO_2 *itself.* The rationale for this is that because most abatement methods are specific to NO_x, they are not designed to control other co-pollutants, and may even increase their emissions. If, instead, NO_2 is monitored as a marker for the concentrations and risks of the complex combustion generated pollution mixtures, a lower annual guideline value than 40 μg/m^3 should be used instead.

There is still no robust basis for setting an annual average guideline value for NO_2 through any direct toxic effect. Epidemiological evidence has emerged, however, that increases the concern over

health effects associated with outdoor air pollution mixtures that include NO_2. These studies have shown for example, that bronchitic symptoms of asthmatic children increase in association with annual NO_2 concentration, and that reduced lung function growth in children is linked with increased NO_2 concentrations within communities already at current North American and European urban ambient air levels. Recently published studies document that NO_2, as marker of a complex mixtures of traffic-related combustion pollution, can have higher spatial variation than particle mass. In addition, these studies reported adverse effects on the health of children living in the areas characterized by higher levels of NO_2 even when the overall level was low. Furthermore, recent studies on indoor NO_2 concentrations have added evidence on adverse effects of NO_2 on respiratory symptoms in children. The WHO AQG 2000 annual average NO_2 guideline value of 40 $\mu g/m^3$ is within the exposure ranges reported in these investigations. They also show that these associations cannot be completely explained by co-exposure to PM, but that other components in the mixture (such as organic carbon and nitrous acid vapour) might explain part of the association. Since such components are not routinely measured, and NO_2 concentrations in ambient air are readily available, it seems reasonable to retain a prudent annual average limit value for NO_2. Such a limit takes into account that there may be direct toxic effects of chronic NO_2 exposure at low levels. In addition, the annual guideline value may help to control complex mixtures of combustion-related pollution (mainly from road traffic).

In experimental studies the lowest level of nitrogen dioxide exposure reported in more than one laboratory shows a direct effect on pulmonary function in asthmatics at 560 $\mu g/m^3$. Studies of bronchial responsiveness among asthmatics indicate an increase in responsiveness at levels upwards from 200 $\mu g/m^3$. The WHO AQG 2000 short term NO_2 guideline of 200 $\mu g/m^3$ is not challenged by more recent studies, and should therefore remain.

Sulfur dioxide

Short-term exposures

Controlled studies with exercising asthmatics indicate that some of them experience changes in pulmonary function and respiratory symptoms after periods of exposure as short as 10 minutes. Based on this evidence, it is recommended that a value of **500 $\mu g/m^3$** should not be exceeded over **averaging periods of 10 minutes**. Because exposure to sharp peaks depends on the nature of local sources and meteorological conditions, no single factor can be applied to this value in order to estimate corresponding guideline values over somewhat longer periods, such as an hour.

Exposure over a 24-hour period and long-term exposure

Day-to-day changes in mortality, morbidity or lung function related to 24-hour average concentrations of sulfur dioxide are necessarily based on epidemiological studies in which people are in general exposed to a mixture of pollutants, with little basis for separating the contributions of each to the effects, which is why guideline values for sulfur dioxide were linked before 1987 with corresponding values for particulate matter. This approach led to a guideline value before 1987 of 125 $\mu g/m^3$ as a 24-hour average, after applying an uncertainty factor of 2 to the lowest-observed-adverse-effect level. In the 2000 revision, it was noted that recent epidemiological studies showed separate and independent adverse public health effects for particulate matter and sulfur dioxide, and this led to a separate WHO AQG for sulfur dioxide of 125 $\mu g/m^3$ as a 24-hour average. More recent evidence, beginning with the Hong Kong study (Hedley et al, 2002) of a major reduction in sulfur content in fuels over a very short period of time, shows an associated substantial reduction in health effects (childhood respiratory disease and all age mortality outcomes). In time-series studies on hospital admissions for cardiac disease, there is no evidence of a concentration threshold within the range of 5-40 $\mu g/m^3$ in both Hong Kong and London (Wong et al, 2002). Daily SO_2 was significantly associated with daily mortality in 12 Canadian cities with an average concentration of only 5 $\mu g/m^3$ (Burnett et al, 2004). If there were an SO_2 threshold for either the Burnett et al. study of daily mortality, or the annual mortality study of Pope et al. (2002), they would have to be very low. For the significant associations in the ACS cohort for 1982-1998 in 126 US metropolitan areas, the mean SO2 was 18 $\mu g/m^3$ (Pope et al, 2002).

Nevertheless, there is still considerable uncertainty as to whether sulfur dioxide is the pollutant responsible for the observed adverse effects or, rather, a surrogate for ultra-fine particles or some other correlated substance. For example, in Germany (Wichmann et al. 2000) and the Netherlands (Buringh et al. 2000) a strong reduction of SO2 concentrations occurred over a decade. Although mortality also decreased with time, the association of SO2 and mortality was judged to not be causal and was attributed to a similar time trend of a different pollutant (PM). In consideration of: (1) the uncertainty of SO2 in causality; (2) the practical difficulty of reaching levels that are certain to be associated with no effects; and (3) the need to provide greater degrees of protection than those provided by the guidelines published in 2000, and assuming that reduction in exposure to a causal and correlated substance is achieved by reducing sulfur dioxide concentrations, then there is a basis for revising the 24 hour guideline downward for sulfur dioxide, and the following guideline is recommended as a prudent precautionary level:

Sulfur dioxide:

20 µg/m^3 for 24-hour mean.
500 µg/m^3 for 10-minute mean (unchanged)

An annual guideline is not needed, since compliance with the 24-hour level will assure low levels for the annual average.

Table 4. SO_2 Air quality guidelines and interim targets to be achieved in improving air quality

	24-hour average SO_2	**10-minute average SO_2**
WHO interim target-1 (IT-1) (2000 AQG level)	125 µg/m^3	-
WHO interim target-2 (IT-2)	50 µg/m^3 Intermediate goal based on controlling either (1) motor vehicle (2) industrial emissions and/or (3) power production; this would be a reasonable and feasible goal to be achieved within a few years for some developing countries and lead to significant health improvements that would justify further improvements (such as aiming for the guideline).	-
WHO Air quality guidelines (AQG)	**20 µg/m^3**	**500 µg/m^3**

For the 24-hour guideline, which may be quite difficult for some countries to achieve in the short term, we suggest a stepped approach using interim goals as shown in table 4.

For instance, a country could move towards guideline compliance by controlling emissions from one major source at a time, selecting among motor vehicle sources, industrial sources and power sources, for the greatest effect on SO_2 at the lowest cost, and monitor public health and SO_2 levels for health effect gains. Demonstrating health benefits will provide an incentive to mandate controls for the next major source category.

These recommended guideline values for sulfur dioxide are not linked with guidelines for particles.

Summary of the updated AQG levels

Table 5 summarizes the updated WHO Air quality guideline levels presented in the previous sections. They are recommended to be achieved everywhere in order to significantly reduce the adverse health effects of pollution.

Table 5. Updated WHO Air quality guideline values

Pollutant	Averaging time	AQG value
Particulate matter		
$PM_{2.5}$	1 year 24 hour (99^{th} percentile)	10 µg/m^3 25 µg/m^3
PM_{10}	1 year 24 hour (99^{th} percentile)	20 µg/m^3 50 µg/m^3
Ozone, O_3	8 hour, daily maximum	100 µg/m^3
Nitrogen dioxide, NO_2	1 year 1 hour	40 µg/m^3 200 µg/m^3
Sulfur dioxide, SO_2	24 hour 10 minute	20 µg/m^3 500 µg/m^3

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Annex 1

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Part 1. Application of AQG for policy development and risk reduction		
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5	Determinants of susceptibility	Mark Utell (United States) Mark Frampton (United States)
6	Environmental equity	Patrick Kinney (United States)
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8	Applications of guidelines in policy formulation	Adrian Fernandez (Mexico) Miriam Zuk (Mexico)
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Part 2. Risk assessment of selected pollutants		
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