Air quality guidelines and their rationale

Particulate matter

Guidelines	
$PM_{2.5}$:	**10 μg/m³ annual mean** **25 μg/m³ 24-hour mean**
PM_{10}:	**20 μg/m³ annual mean** **50 μg/m³ 24-hour mean**

Rationale

The evidence on airborne particulate matter (PM) and its public health impact is consistent in showing adverse health effects at exposures that are currently experienced by urban populations in both developed and developing countries. The range of health effects is broad, but are predominantly to the respiratory and cardiovascular systems. All population is affected, but susceptibility to the pollution may vary with health or age. 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 low end of the range of concentrations at which adverse health effects has been demonstrated is not greatly above the background concentration, which for particles smaller than 2.5 μm ($PM_{2.5}$) has been estimated to be 3–5 μg/m³ in both the United States and western Europe. The epidemiological evidence shows adverse effects of PM following both short-term and long-term exposures.

As thresholds have not been identified, and given that there is substantial inter-individual variability in exposure and in the response in a given exposure, it is unlikely that any standard or guideline value will lead to complete protection for every individual against all possible adverse health effects of particulate matter. Rather, the standard-setting process needs to aim at achieving the lowest concentrations possible in the context of local constraints, capabilities and public health priorities. Quantitative risk assessment offers one way of comparing alternative control scenarios and of estimating the residual risk associated with a particular guideline value. Both the United States Environmental Protection Agency and the European Commission have recently used this approach to revise their air quality standards for PM. Countries are encouraged to consider adopting an increasingly stringent set of standards, tracking progress through the monitoring of emission reductions and declining concentrations of PM. To assist this process, the numerical guideline and interim target values given here reflect the concentrations at which increased mortality responses due to PM air pollution are expected based on current scientific findings.

The choice of indicator for particulate matter also requires consideration. At present, most routine air quality monitoring systems generate data based on the measurement of PM_{10} as opposed to other particulate matter sizes. Consequently, the majority of epidemiological studies use PM_{10} as the exposure indicator. PM_{10} represents the particle mass that enters the respiratory tract and, moreover, it includes both the coarse (particle size between 2.5 and 10 μm) and fine particles (measuring less than 2.5 μm, $PM_{2.5}$) that are considered to contribute to the health effects observed in urban environments. The former is primarily produced by mechanical processes such as construction activities, road dust re-suspension and wind, whereas the latter originates primarily from combustion sources. In most urban environments, both coarse and fine mode particles are present, but the proportion of particles in these two size ranges is likely to vary substantially between cities around the world, depending on local geography, meteorology and specific PM sources. In some areas, the combustion of wood and other biomass fuels can be an important source of particulate air pollution, the resulting combustion particles being largely in the fine ($PM_{2.5}$) mode. Although few epidemiological studies have compared the relative toxicity of the products of fossil fuel and biomass combustion, similar effect estimates are found for a wide range of cities in both developed and developing countries. It is, therefore, reasonable to assume that the health effects of $PM_{2.5}$ from both of these sources are broadly the same. By the same token, the WHO AQG for PM can also be applied to the indoor environment, specifically in the developing world, where large populations are exposed to high levels of combustion particles derived from indoor stoves and fires.

Although PM_{10} is the more widely reported measure, and also the indicator of relevance to the majority of the epidemiological data, for reasons that are discussed below, the WHO AQGs for PM are based on studies that use $PM_{2.5}$ as an indicator. The $PM_{2.5}$ guideline values are converted to the corresponding PM_{10} guideline values by application of a $PM_{2.5}/PM_{10}$ ratio of 0.5. A $PM_{2.5}/PM_{10}$ ratio of 0.5 is typical of developing country urban areas and is at the bottom of the range found in developed country urban areas (0.5–0.8). When setting local standards, and assuming the relevant data are available, a different value for this ratio, i.e. one that better reflects local conditions, may be employed.

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

Long-term exposures

An annual average concentration of 10 $\mu g/m^3$ was chosen as the long-term guideline value for $PM_{2.5}$. This represents the lower end of the range over which significant effects on survival were observed in the American Cancer Society's (ACS) study (Pope et al., 2002). Adoption of a guideline at this level places significant weight on the long-term exposure studies that use the ACS and the Harvard Six-Cities data (Dockery et al., 1993; Pope et al., 1995; HEI, 2000, Pope et al., 2002, Jerrett, 2005). In all of these studies, robust associations were reported between long-term exposure to $PM_{2.5}$ and mortality. The historical mean $PM_{2.5}$ concentration was 18 $\mu g/m^3$ (range, 11.0–29.6 $\mu g/m^3$) in the Six-Cities study and 20 $\mu g/m^3$ (range, 9.0–33.5 $\mu g/m^3$) in the ACS study. Thresholds were not apparent in any 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 $\mu g/m^3$, below which the confidence bounds significantly widen since the concentrations are relatively far from the mean. According to the results of the Dockery et al. (1993) study, the risks are similar in the cities with the lowest long-term $PM_{2.5}$ concentrations (i.e. 11 and 12.5 $\mu g/m^3$). Increases in risk are apparent in the city with the next-lowest long-term $PM_{2.5}$ mean (i.e. 14.9 $\mu g/m^3$), indicating that health effects can be expected when annual mean concentrations are in the range of 11–15 $\mu g/m^3$. Therefore, an annual mean concentration of 10 $\mu g/m^3$ can be considered, according to the available scientific literature, to be below the mean for most likely effects. Selecting a long-term mean $PM_{2.5}$ concentration of 10 $\mu g/m^3$ also places some weight on the results of daily exposure time-series studies that examine the relationships between exposure to $PM_{2.5}$ and acute adverse health outcomes. In these studies, long-term (i.e. three- to four-year) means are reported to be in the range of 13–18 $\mu g/m^3$. Although adverse effects on health cannot be entirely ruled out below these levels, the annual average WHO AQG value represents that concentration of $PM_{2.5}$ that has not only been shown to be achievable in large urban areas in highly developed countries, but also the attainment of which is expected to significantly reduce the health risks.

Besides the guideline value, three interim targets (IT) are defined for $PM_{2.5}$ (see Table 1). These have been shown to be achievable with successive and sustained abatement measures. Countries may find these interim targets particularly helpful in gauging progress over time in the difficult process of steadily reducing population exposures to PM.

An annual mean $PM_{2.5}$ concentration of 35 μg/m^3 was selected as the IT-1 level. This level corresponds to the highest mean concentrations reported in studies of long-term health effects, and may also reflect higher but unknown historical concentrations that may have contributed to 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 set at 25 μg/m^3 and relies, as its basis, on the studies of long-term exposure and mortality. This value is greater than the mean concentration at which effects have been observed in such studies, and is likely to be associated with significant health impacts from both long-term and daily exposures to $PM_{2.5}$. Attainment of this IT-2 value would reduce the health risks of long-term exposure by about 6% (95% CI, 2–11%) relative to the IT-1 value. The recommended IT-3 level is 15 μg/m^3 and places even greater weight on the likelihood of significant effects associated with long-term exposures. This value is close to the mean concentrations that are reported in studies of long-term exposure and provides an additional 6% reduction in mortality risk relative to the IT-2 value.
Corresponding AQGs and interim targets are also recommended for PM_{10} (Table 1). This is because a $PM_{2.5}$ guideline alone would not provide protection against the harmful effects of coarse PM (the fraction between 10 and 2.5 μm). However, the quantitative evidence on coarse PM is considered insufficient to derive separate guidelines. In contrast, there is a large body of literature on effects of short-term exposures to PM_{10}, which has been used as a basis for the development of WHO AQGs and interim targets for 24-hour concentrations of PM (see below).

Table 1

WHOair quality guidelines and interim targets for particulate matter: annual mean concentrations[a]

	PM_{10} (μg/m^3)	$PM_{2.5}$ (μg/m^3)	Basis for the selected level
Iinterim target-1 (IT-1)	70	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2–11%] relative to theIT-1 level.
Interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% [2-11%] relative to the -IT-2 level.
Air quality guideline (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 long-term exposure to $PM_{2.5}$.

[a] The use of $PM_{2.5}$ guideline value is preferred.

Short-term exposures
Whether the 24-hour or the annual average AQG, is the more restrictive tends to vary between countries, this being largely dependent on the specific characteristics of pollutant sources and their location. When evaluating the WHO AQGs and interim targets, it is generally recommended that the annual average take precedence over the 24-hour average since, at low levels, there is less concern about episodic excursions. Meeting the guideline values for the 24-hour mean will however protect against peaks of pollution that would otherwise lead to substantial excess morbidity or mortality. It is recommended that countries with areas not meeting the 24-hour guideline values undertake immediate action to achieve these levels in the shortest possible time.

Multi-city studies conducted in Europe (29 cities) and in the United States (20 cities) reported short-term mortality effects for PM_{10} of 0.62% and 0.46% per 10 μg/m^3 (24-hour mean), respectively (Katsouyanni et al., 2001; Samet et al., 2000). A meta-analysis of data from 29 cities located outside western Europe and North America found a mortality effect of 0.5% per 10 μg/m^3 (Cohen et al., 2004), very similar in fact to that derived for Asian cities (0.49% per 10 μg/m^3)(HEI International Oversight Committee, 2004). These findings suggest that the health risks associated with short-term exposures to PM_{10} are likely to be similar in cities in developed and developing countries, producing an increase in mortality of around 0.5% for each 10 μg/m^3 increment in the daily concentration. Therefore, a PM_{10} concentration of 150 μg/m^3 would be expected to translate into 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 μg/m^3 would be associated with approximately a 2.5% increase in daily mortality, and the IT-3 level with a 1.2% increase (Table 2). For PM_{10}, the AQG for the 24-hour average is 50 μg/m^3, and reflects the relationship between the distributions of 24-hour means (and its 99th percentile) and annual average concentrations.

Table 2

WHO air quality guidelines and interim targets for particulate matter: 24-hour concentrations[a]

	PM_{10} (μg/m^3)	$PM_{2.5}$ (μg/m^3)	Basis for the selected level
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 the AQG value).
Interim target-2 (IT-2)	100	50	Based on published risk coefficients from multi-centre studies and meta-analyses (about 2.5% increase of short-term mortality over the AQG value).
Interim target-3 (IT-3)*	75	37.5	Based on published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase in short-term mortality over the AQG value).
Air quality guideline (AQG)	**50**	**25**	Based on relationship between 24-hour and annual PM levels.

[a] 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. The frequency distribution of daily $PM_{2.5}$ or PM_{10} values usually approximates to a log-normal distribution.

Ultrafine particles (UF), i.e. particles smaller than 0.1 µm in diameter, have recently attracted significant scientific and medical attention. These are usually measured as a 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 of UF particles. Therefore no recommendations can be provided as to guideline concentrations of UF particles at this point in time.