MEAN ANNUAL EXPOSURE OF CHILDREN AGED 0-4 YEARS TO ATMOSPHERIC PARTICULATE POLLUTION	
GENERAL CONSIDERATIONS	
Issues	Respiratory disease
Type of indicator	Exposure (proximal) Can also be used as a measure of action for air quality policies.
Rationale	Exposure to air pollution in the ambient environment poses severe health risks for children. Short periods of high level exposure are known to be implicated in acute respiratory responses (e.g. reduced lung function, wheezing, asthma attacks). These risks are exacerbated, in many cases, by the relatively long periods of time that children often spend outdoors and their small stature – which means that they are inhaling more polluted air than that inhaled by adults. Sensitization to air pollution at an early age may also increase long-term susceptibility to air pollution and contribute to risks of chronic health effects in later life. Many different sources may contribute to ambient emissions of air pollution, including road traffic, industry, agriculture, waste activities and natural processes. Many different pollutants may also pose risks to children's health, including particulates, nitrogen oxides, carbon monoxide, sulphur oxides, ozone, volatile organic compounds (e.g. benzene, a-pryobenzene), metals (e.g. lead, cadmium, mercury) and organic agents (e.g. pollen, infectious organisms). These may act individually or in combination to affect health: for example interactions appear to occur between exposures to air pollution and pollen. Developing general indicators which capture these complex risk factors within a single measure is, therefore, difficult, and indicators may need to be adapted to reflect specific circumstances (e.g. the range of pollutants or emission sources that occur locally). Fine particles, however, represent one of the most important pollutants in terms of respiratory illness, and also act as relatively reliable markers for a number of other pollutants. Exposures to particles, therefore, provides a useful indicator of risks from air pollution.
Issues in indicator design	Various ways can be devised for defining this indicator, but the best is probably in terms of the average exposure of young children to atmospheric particulates. Children in the age range of 0-4 years are especially sensitive to air pollution, so should provide the target group. Several difficulties nevertheless occur in developing the indicator in this way. One is the lack of any universally adopted means of either defining or measuring atmospheric particulates. Common definitions include total suspended particulates (TSP), PM_{10} (i.e. particles with a median equivalent diameter of 10 μm), $PM_{2.5}$ and black smoke. Each of these represents a different size (and thus compositional) fraction of the particles found in the atmosphere, and each may have somewhat different health implications. Measurement methods also vary: typically particles are measured gravimetrically (as a measure of mass), by optical techniques (often as a particle count) or by reflectance (e.g. black smoke). Data provided by these different methods are not directly comparable, and attention therefore needs to be given to the data characteristics when constructing the indicator. Although much of the epidemiological research on respiratory illness has focused on the PM_{10} fraction, more recent findings have tended to emphasize the importance of the finer fraction (e.g. $PM_{2.5}$ or PM_1). These finer fractions, however, are less widely monitored than PM_{10}. There is also some new evidence to suggest that black smoke (or elemental carbon) is a

	good measure of the inhalable fraction of greatest concern. Concentrations of black smoke and PM_{10} also tend to be quite closely correlated, so they can, to some extent, be substituted for each other as a basis for indicator development. Local calibration of this association may be necessary, however, to provide an appropriate adjustment factor. Difficulties also arise in estimating exposures. Monitoring of particulate concentrations is often sparse: even in large cities there may be only one or a few monitors to represent several million people; in rural areas, monitoring may be almost non-existent. Monitoring stations are also often highly biased in their distribution towards certain types of site (often depending on their specific purpose). As a consequence, simply averaging data from several monitoring sites, or using the nearest site to represent exposures, can be highly misleading. Instead, sites need to be selected that are considered representative of exposures, or more sophisticated modelling methods should be used to estimate population-weighted exposures. Differences in these assessment techniques can again be a source of inconsistency in the indicator. A further consideration is the averaging period to use for exposure assessment. Air pollution has both acute and chronic effects. Acute effects are often exacerbated by short periods of raised pollution, which are best represented by daily peak exposures. Chronic effects may be due to long-term exposures, perhaps over many years. These are best represented by average annual exposures. Though short- and long-term exposures tend to be loosely related (because short-term peaks tend to occur in areas which are also more polluted in the long-term), they do not always give comparable classifications of exposure within a population. Average annual exposures are, however, probably easier to assess and more reliable, because they are less sensitive to short term meteorological conditions or behavioural patterns, that may affect exposures from day to day.
SPECIFICATION	
Definition	Mean annual exposure of children aged 0-4 years to atmospheric particulate pollution.
Terms and concepts	***Mean annual exposure:*** the mean, population-weighted exposure, averaged over a year. ***Atmospheric particulate pollution:*** ambient concentrations of PM_{10} (or their equivalent).
Data needs	Mean annual concentrations of PM_{10} at a standard height (usually ca. 2 metres); or mean annual concentrations of black smoke (or TSP) and a locally validated calibration factor to convert this to PM_{10} equivalent Numbers of resident children aged 0-4 years.
Data sources, availability and quality	Data on particulate (or black smoke) concentration can usually be obtained from monitoring networks, run either by national or municipal agencies. As noted above, variations in the definition of the target pollutant and the monitoring methods may exist, and the sites may not be representative of population exposures. Representative sites should thus be selected where necessary. Monitoring is also not always carried out continuously, so data may need to be adjusted to provide estimates of mean annual concentrations. Conversion factors for translating black smoke or TSP concentrations into PM_{10} equivalent are often available from previous studies, or can be obtained by analysing data from co-located monitors. Data on numbers of resident children are usually available from national censuses and should be relatively reliable.
Level of spatial aggregation	Community, administrative area or municipality

Averaging period	Annual (or seasonal, where strong seasonal differences occur)
Computation	Computation of the indicator requires monitoring data to be linked to population distribution, to give a population-weighted measure of mean annual exposure. With the aid of GIS techniques, this can best be done by identifying sites that are representative of residential areas, and then either: 1) averaging these to provide a measure of exposure across the population as a whole; or 2) interpolating between these sites using geostatistical or other techniques, then intersecting the resulting map with the population distribution to derive a population-weighted exposure measure. The latter is likely to be more reliable, so long as a sufficient number of monitoring sites are available. By method 1, therefore, the indicator is computed as: $\Sigma (Pres / Nres)$ where: *Pres* is the annual concentration of particulates measured at each site considered to represent residential locations in the area; *Nres* is the number of residential monitoring sites in the area. By method 2, the indicator is computed as: $\Sigma (Psub * Csub) / Ctot$ where: *Psub* is the annual concentration of particulates in each subarea for which as estimate can be made; *Csub* is the population of children aged 0-4 years in each subarea for which an estimate can be made; *Ctot* is the number of children aged 0-4 years resident in all the subareas.
Units of measurement	Concentration ($\mu g/m^3$ or ppb)
Worked example	By method 1, assume that there are five monitoring stations within a city, of which three are considered to be representative of residential areas. Assume, also, that the annual concentration measured in each of these is 60, 75 and 110 $\mu g/m^3$. In this case, the value of the indicator is calculated as: $(60 + 75 + 110) / 3 = 81.7\ \mu m/m^3$ By method 2, assume that data from these three stations have been interpolated to give estimates for seven subareas in the city, with concentrations (and resident populations of children) as follows: subarea A = 30 $\mu m/m^3$ (910 children) subarea B = 45 $\mu m/m^3$ (1200 children) subarea C = 50 $\mu m/m^3$ (600 children) subarea D = 80 $\mu m/m^3$ (720 children) subarea E = 97 $\mu m/m^3$ (320 children) subarea F = 120 $\mu m/m^3$ (1 400 children) subarea G = 135 $\mu m/m^3$ (260 children) In this case the value of the indicator would be calculated as: $[(30*910)+(45*1200)+(50*600)+(80*720)+(97*320)+(120*1400)+(135*260)] / 5\,400 = 74.6\ \mu m/m^3$
Interpretation	This indicator can be interpreted as a measure of children's exposures to ambient atmospheric particular pollution. The main sources of this pollution are likely to be combustion sources such as road traffic, industry, domestic

	heating and forest fires. An increase in the indicator can be interpreted as evidence of increased exposure to pollution from these sources, and a consequent increase in risks to respiratory health; a reduction in the indicator implies a decline in exposures and associated health risks. Several factors nevertheless need to be considered in using the indicator. The first is that particulate pollution is only one component of air pollution, and not always the most important in terms of respiratory illness. Other pollutants – e.g. ozone, NO_2 and other particle size fractions– may also be important in some cases. Secondly, the uncertainties inherent in the data need to be recognized – in particular, where monitoring stations are sparse so that data have had to be extrapolated over large areas in order to derive exposure measures. Thirdly, it needs to be remembered that populations may differ substantially in terms of their susceptibility to these exposures (e.g. due to differences in general health or past exposure history), so areas or periods of higher pollution do not always imply increased health risk. Finally, it needs to be noted that ambient air pollution is often not the main source of exposure for children: indoor exposures are often far more significant.
Variations and alternatives	Many different variations on this indicator are possible. Obvious alternatives include the use of different measures of particulates (e.g. TSP, $PM_{2.5}$) or other pollutant species (e.g. NO_2, SO_2). The indicator can also be measured for shorter averaging times (e.g. daily peak exposure) where appropriate. Where data on population are not available – or extrapolation to give population-weighted measures is not considered appropriate – mean ambient pollutant concentrations of these pollutants can be used as a proxy. It is also possible in principle to compute a measure of exposure to multiple pollutants. If the relative dose-response relationships (or toxicities) of these different pollutants are known, their concentrations can be weighted and averaged to give a combined pollutant index. This can then be adjusted to reflect the numbers of children exposed using the methods outlined above. Alternatively, the different pollutants can be standardized by computing their percentage exceedance of air quality guideline values, before summing to give a measure of exposure. Where guidelines have not been established, mean annual concentrations from a nearby rural site may be used as a reference value.
Examples	UN *Indicators of sustainable development* • **Ambient concentrations of pollutants in urban areas** WHO *Environmental health indicators: framework and methodologies* • **Ambient concentrations of air pollutants in urban areas** WHO *Environmental health indicators for the European region* • **Annual average concentration of NO_2, PM_{10} and SO_2, and 8 hr weighted O_3, in relation to reference values**
Useful references	UN *1996 Indicators of sustainable development. Framework and methodologies*. New York: United Nations. WHO 1999 *Environmental health indicators: framework and methodologies.* Geneva: World Health Organization. (Available at http://www.who.int/docstore/peh/archives/EHIndicators.pdf) WHO 2000 *Air Quality Guidelines for Europe. Second edition.* WHO Regional Publications, European Series No. 91. Geneva: World Health Organization. WHO 2000 *Guidelines for air quality.* Geneva: World Health Organization. WHO 2002 *Environmental health indicators: development of a methodology*

	for the WHO European region. Bonn: World Health Organization. WHO Healthy Cities Air Management Information System (AMIS).