Ground-Level Ozone

Ozone (O_3) is a colorless, reactive oxidant gas that is a major constituent of atmospheric smog. Ground-level ozone is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NO_x), facilitated by a variety of volatile organic compounds (VOCs), which are photochemically reactive hydrocarbons. The relative importance of the various VOCs in the oxidation process depends on their chemical structure and reactivity. Ozone may be formed by the reaction of NO_x and VOCs under the influence of sunlight hundreds of kilometers from the source of emissions.

Ozone concentrations are influenced by the intensity of solar radiation, the absolute concentrations of NO_x and VOCs, and the ratio of NO_x and VOCs. Diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level ozone accumulation occurs when sea breezes cause circulation of air over an area or when temperature-induced air inversions trap the compounds that produce smog (Chilton and Sholtz 1989). Peak ground-level ozone concentrations are measured in the afternoon. Mean concentrations are generally highest during the summer. Peak concentrations of ground-level ozone rarely last longer than two to three hours (WHO 1979).

Registered average natural background concentrations of ground-level ozone are around 30–100 micrograms per cubic meter (μg/m^3). Short-term (one-hour) mean ambient concentrations in urban areas may exceed 300–800 μg/m^3 (WHO 1979).

Main Sources

Both natural and anthropogenic sources contribute to the emission of ground-level ozone precursors, and the composition of emissions sources may show large variations across locations. VOCs occurring naturally due to emissions from trees and plants may account for as much as two thirds of ambient VOCs in some locations (USEPA 1986). Anaerobic biological processes, lightning, and volcanic activity are the main natural contributors to atmospheric NO_x, occasionally accounting for as much as 90% of all NO_x emissions (Godish 1991).

Motor vehicles are the main anthropogenic sources of ground-level ozone precursors. Other anthropogenic sources of VOCs include emissions from the chemical and petroleum industries and from organic solvents in small stationary sources such as dry cleaners. Significant amounts of NO_x originate from the combustion of fossil fuels in power plants, industrial processes, and home heaters.

Health Impacts of Exposure

The main health concern of exposure to ambient ground-level ozone is its effect on the respiratory system, especially on lung function. Several factors influence these health impacts, including the concentrations of ground-level ozone in the atmosphere, the duration of exposure, average volume of air breathed per minute (ventilation rate), and the length of intervals between short-term exposures.

Most of the evidence on the health impacts of ground-level ozone comes from animal studies and controlled clinical studies of humans focusing on short-term acute exposure. Clinical studies have documented an association between short-term exposure to ground-level ozone at concentrations of 200–500 μg/m^3 and mild temporary eye and respiratory irritation as indicated by symptoms such as cough, throat dryness, eye and chest discomfort, thoracic pain, and headache (WHO 1979, 1987). Temporary decrements in pulmonary function have been found in children at hourly average ground-level ozone concentrations of 160–300 µg / m^3. Similar impacts were observed after 2.5-hour exposure of heavily exercising adults and children to concentrations of 240 µg / m^3 (WHO 1987). Lung function losses, however, have been reversible and relatively mild even at concentrations of 360 µg / m^3, with a great variety of personal responses (Chilton and Sholtz 1989). Full recovery of respiratory functions normally occurs within 24 to 48 hours after exposure (WHO 1987).

Animal studies have also demonstrated an inflammatory response of the respiratory tract following exposure to ground-level ozone at 1,000 µg / m^3 for four hours (WHO 1987). Although biochemical and morphological alterations in the red blood cells were found in several animal species after exposure to ground-level ozone concentrations of 400 µg / m^3 for four hours (WHO 1987), no consistent changes have been demonstrated in humans, even at concentrations as high as 1,200 µg / m^3 (USEPA 1986), and extrapolation of such impacts to humans has not been supported.

Exposure to elevated concentrations of ground-level ozone has been shown to reduce physical performance, since the increased ventilation rate during physical exercise increases the effects of exposure to ground-level ozone. There is no evidence that smokers, children, older people, asthmatics, or individuals with chronic obstructive lung disease are more responsive to ground-level ozone exposure than others. Ground-level ozone may, however, make the respiratory airways more responsive to other inhaled toxic substances and bacteria. In addition, a synergistic effect of ground-level ozone and sulfur dioxide has been found, indicating that sulfur dioxide potentiates the effects of ground level ozone (WHO 1979).

Besides short-term impacts, the potential for irreversible damage to the lungs from repeated exposure over a longer period of time has been a health concern. Some studies have found an association between accelerated loss of lung function over a longer period of time (five years) and high oxidant levels in the atmosphere (Detels et al. 1987). WHO (1987) pointed out that the length of the recovery period between successive episodes of high ground-level ozone concentrations and the number of episodes in a season may be important factors in the nature and magnitude of health impacts, since prolonged acute exposure to ground level ozone concentrations of 240–360 µg / m^3 resulted in progressively larger changes in respiratory function. However, a cross-sectional analysis based on large samples from multiple locations in the United States (Schwartz 1989) found no correlation between chronic ground-level ozone pollution and reduced lung function except for the highest 20% of ground-level ozone exposures, suggesting the possibility of a lower threshold for effects of chronic ground-level ozone exposure. No evidence has been found of an association between peak oxidant concentrations and daily mortality rates of the general population (WHO 1979).

Other Impacts

Elevated ground-level ozone exposures affect agricultural crops and trees, especially slow-growing crops and long-lived trees. Ozone damages the leaves and needles of sensitive plants, causing visible alterations such as defoliation and change of leaf color. In North America, tropospheric ozone is blamed for about 90% of the damage to plants. Agricultural crops show reduced plant growth and decreased yield. According to the U.S. Office of Technology Assessment (OTA 1988), a 120 µg / m^3 seasonal average of seven-hour mean ground-level ozone concentrations is likely to lead to reductions in crop yields in the range of 16–35% for cotton, 0.9–51% for wheat, 5.3–24% for soybeans, and 0.3–5.1% for corn. In addition to physiological damage, ground-level ozone may cause reduced resistance to fungi, bacteria, viruses, and insects, reducing growth and inhibiting yield and reproduction. These impacts on sensitive species may result in declines in agricultural crop quality and the reduction of biodiversity in natural ecosystems.

The impact of the exposure of plants to ground-level ozone depends not only on the duration and concentration of exposure but also on its frequency, the interval between exposures, the time of day and the season, site-specific conditions, and the developmental stage of plants. Furthermore, ground-level ozone is part of a complex relationship among several air pollutants and other factors such as climatic and meteorological conditions and nutrient balances. According to some studies, for example, the presence of sulfur dioxide may increase the sensitivity of plants to leaf injury by ground-level ozone (WHO 1987). Reinert and Heck (1982) point out that the presence of ground-level ozone may increase the growth-suppressing effects of nitrogen dioxide.

Ambient Standards and Guidelines

Ambient standards and guidelines for ground-level ozone are aimed at protecting human health, sensitive ecosystems, and agricultural plants from the harmful effects of ground-level ozone. Table 1 presents USEPA, California, and WHO reference standards and guidelines for ambient ground-level ozone concentrations. Due to uncertainty about chronic effects and the lack of established dose-response function data, these standards and guidelines focus on short-term ground-level ozone concentrations.

Conclusions

Evidence suggests that exposure to short-term peak concentrations of ground-level ozone damages human health but that these impacts are relatively mild and reversible at ground-level ozone levels exceeding current U.S. and WHO standards and guidelines. Although repeated exposure to peak concentrations may result in cumulative impacts on lung function, inhibiting recovery, no clear evidence for such chronic effects of ground-level ozone exists. The large variety of sources and factors contributing to the formation of ground-level ozone, differences in the sensitivity and response of affected receptors, and variations in the costs and benefits of achieving certain air quality requirements for ground-level ozone may call for area-specific guide values.

Table 1. Reference Standards and Guidelines for Ambient Atmospheric Ozone Concentrations
(micrograms per cubic meter)

Standard or guideline	*Short-term (1 hour) average*	*Medium-term (8 hour) average*
USEPA	2,35[a]	
State of California	1,80[a]	
WHO (1979)	100–200	
WHO guidelines for Europe (1987)	150–200	100–120

a. Value not to be exceeded more than once a year.
Sources: USEPA 1986; WHO 1979, 1987.

Since ground-level ozone is formed by the photochemical reaction of nitrogen oxides and certain hydrocarbons, abatement strategies should focus not only on reduction of emissions of these substances but also on their ratio and balance. In areas where NO_x concentrations are high relative to VOCs, the abatement of VOC emissions can reduce the formation of ground-level ozone, while reduction in nitrogen oxides may actually increase it. In areas where the relative concentration of VOCs is high compared with nitrogen oxides, ground-level ozone formation is "NO_x-limited," and NO_x reductions work better than VOC abatement (OTA 1989).

Recommendations

In the long term, countries should seek to ensure that ambient exposure to ground-level ozone does not exceed the guidelines recommended by WHO (see Table 1). In the interim, countries should set ambient standards for ground-level ozone that take into account the benefits to human health and to sensitive ecosystems of reducing exposure to ground-level ozone; the concentration levels achievable by pollution prevention and control measures; and the costs involved in meeting the standards. In adopting new ambient air quality standards, countries should set appropriate phase-in periods during which districts or municipalities that do not meet the new standards are expected and will be assisted to attain these standards. Where there are large differences in either the costs or the benefits of meeting air quality standards, it may be appropriate to establish area-specific ambient standards case by case.

Prior to carrying out an environmental assessment (EA), a trigger value for annual average concentrations of ground-level ozone should be agreed on by the country and the World Bank. Countries may wish to adopt EU, USEPA, or WHO guidelines or standards as their trigger values. The trigger value should be equal to or lower than the country's ambient standard. The trigger value is not an ambient air quality standard but simply a threshold. If, as a result of the project, the trigger value is predicted to be exceeded in the area affected by the project, the EA should seek mitigation alternatives on a regional or sectoral basis.

In addition, good practice in airshed management should encompass the establishment of an emergency response plan during industrial plant operation. It is recommended that this plan be put into effect when levels of air pollution exceed one or more of the emergency trigger values determined for short-term concentrations of sulfur dioxide, nitrogen oxides, particulates, and ground-level ozone. The recommended emergency trigger value for ground-level ozone is 150 $\mu g / m^3$ for one-hour average concentrations.

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