Health Canada | Santé Canada
Environment Canada | Environnement Canada

NATIONAL AMBIENT AIR QUALITY OBJECTIVES FOR CARBON MONOXIDE

Executive Summary

DESIRABLE, ACCEPTABLE & TOLERABLE LEVELS

Prepared by the CEPA/FPAC Working Group on Air Quality Objectives and Guidelines

Canada

NATIONAL AMBIENT AIR QUALITY OBJECTIVES FOR CARBON MONOXIDE

Desirable, Acceptable & Tolerable Levels

EXECUTIVE SUMMARY

A Report by the CEPA/FPAC Working Group on Air Quality Objectives and Guidelines

This report is published under Section 8 of the *Canadian Environmental Protection Act* (CEPA). Any inquiries concerning this publication or requests for copies should be directed to either of the following officials:

Director
Science Assessment and
Policy Integration Division
Atmospheric Environment Service
Environment Canada
4905 Dufferin Street
Toronto, Ontario M3H 5T4

Director
Bureau of Chemical Hazards
Environmental Health Centre
Health Canada
Tunney's Pasture
Ottawa, Ontario K1A 0L2

This report has been prepared by the following people:

F. Hopper (Atmospheric Environment Service, Environment Canada)
S. MacDonald (Health Canada)
M. Shepherd (Atmospheric Environment Service, Environment Canada)
K. Wilby (Health Canada)
P. Wong (Ontario Ministry of Environment and Energy)

The Working Group on Air Quality Objectives and Guidelines wishes to acknowledge the following people for their contribution:

M. Bourgeau (Health Canada)
B. Jessiman   (Health Canada)
G. Wood   (Health Canada)

November 1994
ISBN 0-662-25642-5
Catalogue En42-17/1-1997E

Context

The *Canadian Environmental Protection Act* (CEPA), passed into law in 1988, replaces and builds upon the *Clean Air Act* and the *Environmental Contaminants Act*. The opening statement of CEPA declares that "the protection of the environment is essential to the well-being of Canada." CEPA allows the federal government to assess substances and control their impact through national environmental quality objectives, guidelines, codes of practice, and/or regulations.

Provincial governments have the primary responsibility in many areas of air pollution control, with federal actions integrated with those of the provinces. The CEPA Federal–Provincial Advisory Committee Working Group on Air Quality Objectives and Guidelines reviews and recommends ambient air quality objectives. Development follows a process that integrates the review of physical and chemical properties, sources, environmental, animal, and human health effects, and environmental and human exposure assessment within a framework of risk assessment.

Canada's National Ambient Air Quality Objectives (NAAQOs) prescribe targets for air quality, measured at the relevant receptor (persons, plants, animals, materials). These targets may incorporate some element of cost–benefit–risk, reflecting a philosophy of environmental health protection and long-term risk reduction while recognizing technological and economical limits. Consequently, the resulting objectives may be set above a level at which no effects are observed. The objectives are established to provide background information, a uniform scale for assessing the quality of air in all parts of Canada, and guidance to governments for making risk management decisions, such as planning control strategies and setting local standards.

Three ranges of air quality are prescribed — "desirable," "acceptable," and "tolerable." The numerical values for the highest levels of contaminant in each range are based on the following qualitative definitions:

- The **maximum desirable level** is the long-term goal for air quality and provides a basis for an anti-degradation policy for unpolluted parts of the country and for the continuing development of pollution control technology.
- The **maximum acceptable level** is intended to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, and personal comfort and well-being.
- The **maximum tolerable level** denotes time-based concentrations of air contaminants beyond which, owing to a diminishing margin of safety, appropriate action is required without delay to protect the health of the general population.

The process of establishing air quality objectives is a dynamic and continuous one. Ambient air quality objectives were published in the Canada Gazette Part 1 in August, 1989. No changes were made to the objectives which were prescribed between 1974 and 1978 (Fisheries & Oceans, 1971).

This report is a review of the science in support of the desirable, acceptable, and tolerable levels for carbon monoxide (CO) by the CEPA/FPAC Working Group on Air Quality Objectives and Guidelines.

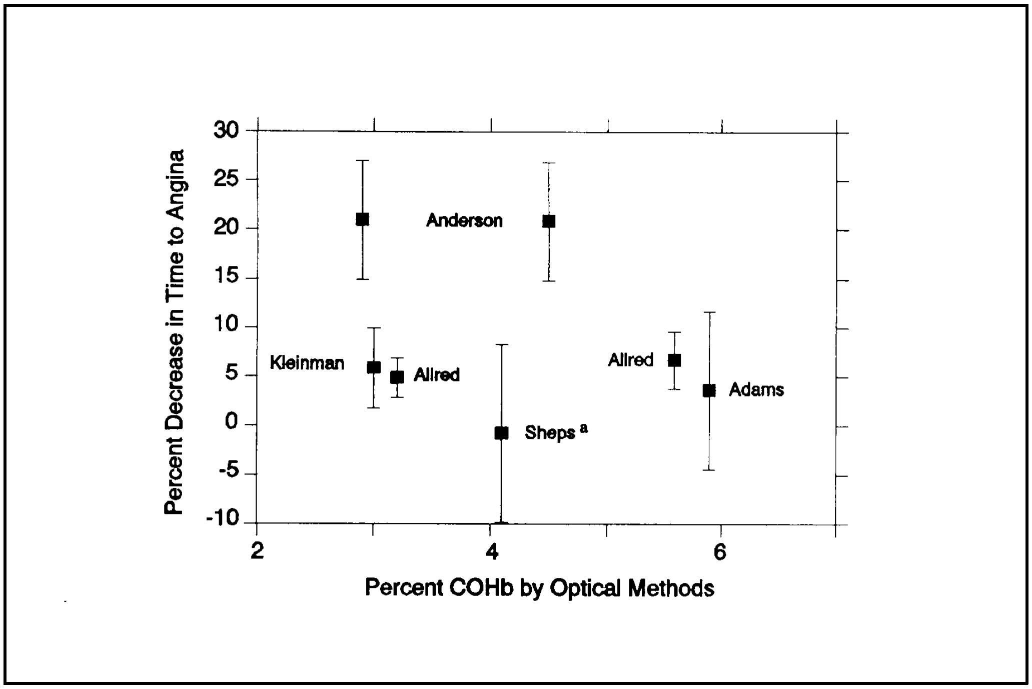
Summary of Scientific Evidence

Cardiorespiratory effects in people with exercise-induced myocardial ischemia are the health effects of greatest concern. Figure 1 illustrates the effect of carbon monoxide exposure on time to onset of angina in the five key studies discussed above in the section entitled "Effects on Human Health". The figure accommodates the most important differences between studies by presenting the data as mean percent differences between air exposures and carbon monoxide exposures for individual subjects from each study, using COHb levels that were measured at the end of the carbon monoxide exposure by optical methods only. Under these conditions, the five studies show a consistent relationship between increasing COHb levels and time to onset of angina. Post-exposure COHb levels ranging from 2.9 to 5.9%, representing incremental increases of 1.5–4.4% COHb from pre-exposure baseline levels, are shown.

These ranges must still be interpreted with caution, owing to differences in study design and the lack of precision in optical measurements of COHb at low blood COHb levels. In addition, studies on cardiorespiratory effects are difficult to interpret, owing to differences in study design, type of exercise test used, criteria used for including patients in the study, and exposure conditions (U.S. EPA, 1991). The time of measurement of COHb levels (i.e., at the end of the carbon monoxide exposure or at the time of the angina) and the methods used for measuring COHb levels (i.e., gas chromatography or spectrophotometry) yield varying results and make it difficult to compare COHb levels reported in different studies. Mennear (1993), for example, stated that the gas chromatographic method used for measuring COHb in the Allred et al. (1989) study may be more precise than the spectrophotometric technique generally used, but that it gives a lower value for COHb, as indicated by the fact that the baseline COHb level in the Allred et al. (1989) study is about half the usual baseline value.

It has been argued that reductions in exercise capacity associated with carbon monoxide exposure lack clinical significance, as the changes are small relative to the range of reproducibility of exercise stress tests used in the various studies. Others have argued that the effects, if real, could limit the daily activities of susceptible individuals and affect their quality of life. Studies showing a relationship between low COHb levels and exercise-induced arrhythmia in patients with coronary artery disease suggest that carbon monoxide exposure may increase the risk of sudden death from arrhythmia. The dose–response relationship between COHb and ischemia reported by Allred et al. (1989) suggests that small increases in COHb levels could adversely affect myocardial function and produce ischemia, and that this relationship may lack a threshold.

Figure 1. **The Effect of Exposure to Carbon Monoxide on the Time to Onset of Angina in Five Key Studies**



Source: U.S. EPA, 1991

Note:
Data are presented as mean percent differences between air and carbon monoxide exposures for individual subjects calculated from each study. Bars indicate calculated standard errors of the mean. Alternative analysis of the Sheps data indicates a significant decrease in time to onset of angina at 4.1% COHb if subjects that did not experience exercise-induced angina during air exposure were included in the analysis.

COHb Levels of Concern

Cardiorespiratory effects have consistently been observed at COHb levels below 6% in the blood and have been associated with carbon monoxide exposures at levels observed in ambient air. On the other hand, neurobehavioural effects and developmental toxicity effects in people have not been reported below COHb levels of 5%. A COHb level in blood as low as 2.9% may be associated with adverse cardiorespiratory effects in individuals with ischemic heart disease. Mennear (1993) reviewed the literature in a study of the possible relationship between carbon monoxide exposure, arising from environmental tobacco smoke, and exacerbation of ischemic heart disease. He determined that a level of 2.5% COHb in blood was a conservative estimate of a no-effect level for carbon monoxide toxicity, even among people having ischemic heart disease. Although the Allred et al. (1989) study reports a lower effect level of 2.0%, as measured by gas chromatography at the end of the exercise test, the measurement technique used has been questioned in terms of its accuracy in measuring absolute COHb levels (Mennear, 1993). Therefore, objectives developed to protect the subpopulation sensitive to cardiorespiratory effects are expected to provide an adequate margin of safety for the general population with respect to neurobehavioural and developmental toxicity effects.

Taking into consideration uncertainties in the available data and using the most conservative assumptions, it is recommended that maximum desirable levels be chosen such that they result in a COHb blood level of less than 1%, which is considered to be in the upper end of the range of baseline COHb levels resulting from endogenous production in normal, non-smoking individuals (Urbanetti, 1981). The maximum acceptable levels should be chosen to result in a COHb blood level of 2.0%, which is the lowest-observed effect level (LOEL) measured by gas chromatography at the end of exercise (Allred et al., 1989). This can be interpreted as providing a margin of safety as it is one third lower than 3% COHb (measured by optical methods at the end of exposure) suggested as a LOEL by Anderson et al. (1973), Kleinman et al. (1989), and Allred et al. (1989). Maximum tolerable levels should be selected such that a blood COHb level of about 2.5%, which is still considered to be a population-based no-effect level in most studies (e.g., Mennear, 1993), is not exceeded.

The PBPK model of Coburn, Forster, and Kane is a reliable method for predicting COHb blood levels for exposure to a given ambient carbon monoxide concentration. This model has been extensively validated over many years. Precision is acceptable, providing that the original conditions of use are rigorously applied. Blood COHb level is influenced by baseline COHb level, blood hemoglobin level, minute ventilation, diffusion capacity of the lungs, and mean oxygen tension in pulmonary capillaries (Coburn et al., 1965), all of which vary among members of the population. As a consequence of these factors, exposure to the same concentration of carbon monoxide may result in different COHb levels in different individuals. Exposure is a function of carbon monoxide concentrations in ambient and indoor air, the duration of exposure to carbon monoxide, as well as initial COHb levels, such that differences in the COHb levels within the population can also be attributed to differences in the levels of exposure and the range of exposures experienced.

Exposure to Carbon Monoxide

The impact of indoor sources on exposure and COHb levels in Toronto has been clearly shown. TimeBactivity pattern studies revealed that people generally spend 20 hours indoors and 4 hours outdoors (U.S. EPA, 1991). People generally experience various carbon monoxide levels during their normal daily activities while changing from one microenvironment to another. The DenverBWashington study results showed that the effects of personal activity and indoor sources have a significant impact on personal exposure (Akland et al., 1985). Cooking with gas increases personal exposure to carbon monoxide, as does working in an office or living in a residence with smoking activity (Ott et al., 1988). While sleeping in the bedroom, people in Los Angeles were exposed to an average of 2.1 ppm (Lambert et al., 1991) and Denver residents were exposed to an average of 1.5 ppm (n = 6681) (Ott et al., 1988). Time spent indoors is therefore an important pathway of exposure to carbon monoxide. Indoor levels of carbon monoxide are influenced by outdoor levels, infiltration and ventilation rates, indoor sources, and air mixing between and within rooms (U.S. EPA, 1991). Outdoor levels of carbon monoxide are a function of the transportation category, which accounts for about 67% of the national carbon monoxide emissions (Kosteltz and Deslauriers, 1990).

Results of the field studies also showed that carbon monoxide levels determined with PEMs were higher than those recorded at fixed-site monitoring stations (Akland et al., 1985; Holland, 1983; Ott & Flachsbart, 1982). Estimates of exposure for the Toronto population in 1991 indicate that less than 1% of the population experienced 1-hour daily maximum averages above 25 ppm; approximately 2% experienced 8-hour daily maximum carbon monoxide exposures above 13 ppm. When compared with exceedances measured at the fixed-site monitors, concentrations and personal exposures averaged over 8-hours were related. Personal exposures to carbon monoxide averaged over 1-hour were not closely related to concentrations measured at the fixed-site.

These results, and others presented earlier, indicate that personal exposure to carbon monoxide does not directly correlate with ambient carbon monoxide concentrations recorded at fixed sites. During their normal daily activities, people move from one microenvironment to another. As described previously, carbon monoxide levels in each of these microenvironments differ, so that people experience various daily carbon monoxide exposures. The greatest carbon monoxide exposure for most people occurs in the vehicle and indoor microenvironments associated with combustion sources (U.S. EPA, 1991). Even though these studies have been performed in the United States, they are still very good indicators of carbon monoxide levels to which Canadian people might be exposed in various microenvironments.

Populations at Risk

Lifestyle and genetic factors combine to increase the likelihood of health effects from carbon monoxide exposure. Age, behaviour, differences in activity patterns, sex, and other factors that determine an individual's ability to deal with environmental insults result in a distribution of response.

Currently available evidence suggests that individuals with heart disease, including stable exercise-induced angina, coronary artery disease, and ischemic heart disease, represent the population at greatest risk from exposure to ambient carbon monoxide levels. In addition, population groups with either increased probability or increased severity of health effects include pregnant women, fetuses and young infants, individuals with anemia or respiratory disease, the elderly, children, and persons with peripheral vascular disease and chronic obstructive lung disease.

The extensive personal exposure field studies revealed that persons working outside the home, persons with high occupational exposure (truck drivers, taxi drivers, bus drivers, automobile mechanics, garage workers, policemen), and commuters — particularly those travelling >6 hours per week — had significantly higher exposures ($p = 0.05$) than their respective counterparts (Akland et al., 1985; Johnson, 1984). In addition, with over 2000 indoor arenas in Canada, professional and recreational athletes, spectators, and workers may be exposed to high levels of carbon monoxide.

Recommendations

The choice of National Ambient Air Quality Objectives for carbon monoxide is based upon the clinical significance of health effects of concern, the number of people requiring protection, and the relationship between COHb levels, exposure, and ambient carbon monoxide levels.

COHb levels are a biomarker for the toxicity of ambient-level exposures to carbon monoxide and are used as an indicator of carbon monoxide exposure. Although more research is needed to evaluate the predictive capabilities of the CFK model in individuals exposed to low concentrations of carbon monoxide and its applicability to sensitive subpopulation (U.S. EPA, 1991), it is the best model available at present, and it will be used here to estimate appropriate National Ambient Air Quality Objectives for carbon monoxide. However, it must be remembered that models provide estimates based upon small numbers of representative measurements.

Recommended National Ambient Air Quality Objectives, ppm (mg/m^3) [a]

Averaging Times	Maximum Desirable Level	Maximum Acceptable Level	Maximum Tolerable Level
1 hour	13 (15)	30 (35)	n/a
8 hours[b]	5 (6)	13 (15)	17.4 (20)

[a] 1 ppm = 1.146 mg CO/m^3
[b] rolling average

The maximum desirable levels are based on the carbon monoxide concentration that will result in a carboxyhemoglobin (COHb) blood level of less than 1%, or the upper end of the range of baseline COHb levels resulting from endogenous production. Based on the Coburn-Foster-Kane (CFK) equation, a 1-hour exposure of 13 ppm or an 8-hour exposure of 5 ppm would lead to less than 1 % COHB.

The recommended maximum acceptable levels for carbon monoxide are 30 ppm averaged over 1-hour and 13 ppm as an 8-hour rolling average. Results from five recent studies in 3 laboratories were consistent in finding adverse effects of COHb levels ranging from 2.9% to 6% (as measured by CO-Oximeter) or as low as 2% (as measured by gas chromatography) on exercise induced angina and on ECG (electrocardiogram) values. CO levels averaging 13 ppm over 8 hours or 30 ppm over 1 hour resulted in COHb levels at or below 2% for adults performing light work (ventilation rate of 18L/m).

Therefore, the maximum acceptable levels are based on the maintenance of COHb levels of less than 2%, thereby providing a small margin of safety. At levels above these concentrations, action would be required to decrease the probability or severity of effects in sensitive populations. Estimating COHb levels using pNEM indicates that less than 1% of the Toronto study area population will experience COHb levels greater than 2.0% if the ambient air quality is less than or equal to 13 ppm (15 mg/m^3) measured over 8 hours.

The recommended maximum tolerable level for an 8 hour exposure could be based on the lowest observed adverse effect level (LOAEL) of 2.9% COHb observed in the same experiments cited previously. This level would be approximately 21 ppm. However, the current tolerable level of 17 ppm is sufficiently close to this value to be retained as the objective.

The recommended maximum tolerable level of 17 ppm averaged over 8 hours will result in a COHb level of about 2.5% as projected by the CFK model. This is still below the COHb levels believed to result in cardiorespiratory effects in the general population. Moreover, it is considered to be slightly more protective in accounting for non-standard conditions and people at the high end of the distribution curve for parameters used in the CFK equation. However, owing to a diminishing margin of safety within the tolerable range, action is recommended without delay when air quality exceeds the highest concentration of this range to protect the health of sensitive subgroups.

The averaging times chosen for the maximum desirable, acceptable, and tolerable ranges of carbon monoxide in ambient air are 1 and 8 hours. The latter averaging time approximates the length of time during which people may be exposed to carbon monoxide continuously in a particular location (e.g., work, sleep). More importantly, most individuals approach equilibrium levels of COHb in the blood after about 8–12 hours of exposure to (Anderson et al., 1973). Owing to the possibility of missing some events (high levels of carbon monoxide exposure) using a continuous averaging time, rolling averages are recommended for the calculation of the 8-hour averages. The 1-hour averaging period is intended to be protective for effects that might occur following short exposures to high concentrations of carbon monoxide.

The five air quality objectives for carbon monoxide recommended in this report are illustrated in Figure 2, together with their associated COHb levels as projected by the CFK model.

Figure 2. Recommended National Ambient Air Quality Objectives for Carbon Monoxide and Predicted COHb Levels