

THE JOURNAL OF Allergy AND Clinical Immunology

August 1994, part 2 • Volume 94 • Number 2

Indoor air pollution: NO, NO₂, CO, and CO₂

W. Michael Alberts, MD [[MEDLINE
LOOKUP](#)]

- *Tampa, Florida*

Sections

- [Oxides of Nitrogen](#)
- [Carbon Monoxide](#)
- [Carbon Dioxide](#)
- [Control of Indoor Air Pollution From
Combustion Sources](#)
- [Conclusion](#)
- [References](#)
- [Publishing and Reprint Information](#)

- [Previous article](#) in Issue
- [Next article](#) in Issue
- [Drug links](#) from Mosby's DrugConsult
- [Genetic information](#) from OMIM
- Citation of this Article
 - View on [PubMed](#)
 - Download in [citation manager format](#)
 - Download in [Medlars format](#)
- [Related articles](#) in PubMed

ASHRAE American Society of Heating, Refrigerating,
and
Air-conditioning Engineers

cfm Cubic feet of air per minute

CO Carbon monoxide

CO₂ Carbon dioxide

COPD Chronic obstructive pulmonary disease

FEV₁ Forced expiratory volume in 1 second

FVC	Forced vital capacity
NO	Nitric oxide
NO₂	Nitrogen dioxide
O₂	Molecular oxygen
ppb	Parts per billion
ppm	Parts per million



The common indoor air pollutants may be categorized in several different ways. In a 1987 state of the art article, Samet et al.¹ divided the major pollutants by origin. They identified three major groups: (1) combustion sources, (2) biologic sources, and (3) other sources (e.g., radon and radon daughters, volatile and semivolatile organic compounds, and formaldehyde) (■Table I). This review will center on indoor air pollution that emanates from combustion sources.

TABLE I. Common indoor air pollutants

Combustion sources
Environmental tobacco smoke
Wood smoke
NO ₂
CO monoxide
Biologic sources
Infectious sources
Allergens
Miscellaneous sources
Radon
Volatile organic compounds
Formaldehyde
Others

The best known and arguably the most important indoor air pollutant is tobacco smoke. Tobacco smoke is an aerosol containing several thousand substances that are distributed as gases, vapors, or particulates.² Environmental tobacco smoke will be discussed in detail elsewhere in this

supplement. It is important to note, however, that tobacco smoke is a major source of indoor nitrogen dioxide (NO₂) and carbon monoxide (CO).

Smoke that emanates from wood stoves and fireplaces is a potential source of several indoor air pollutants. This is a much larger problem in lesser developed nations.³ Approximately half of the world's population still relies on biomass fuels (wood, crop residues, and animal dung) for cooking and heating.⁴ For several reasons (e.g., economic and aesthetic), there has been a resurgence in the use of wood as a fuel in the home in the United States. Wood burning, in addition to producing polycyclic aromatic hydrocarbons and increased respirable particles, is a significant source of indoor CO.

A third major indoor air pollutant from combustion sources is NO₂ and the other oxides of nitrogen, and the fourth category of major indoor air pollutants of this class is CO. Depending on the fuel and the circumstances of combustion, many other substances may result from combustion. These substances may likewise affect the indoor environment but will not be discussed in this article.

Carbon dioxide (CO₂) is a related substance discussed in this review; it is somewhat different in that it is more important as a marker of inadequate air quality than as a specific indoor air pollutant.

This article will concentrate on NO₂, CO, and CO₂. The literature concerning these indoor pollutants is quite extensive and space does not permit a complete review of the relevant studies. Certain studies, however, will be mentioned to highlight general statements and conclusions. Each of the three substances will be discussed in terms of the following: (1) chemistry, (2) common sources, (3) ambient, peak, and danger levels, (4) mechanism of injury, damage, or adverse effect, and (5) clinical manifestations. Current options for the control of these indoor air pollutants will be discussed briefly.

Oxides of Nitrogen

[TOP](#)

Chemistry

Nitric oxide (NO) is a relatively inert gas produced by high-pressure combustion. It arises from the oxidation of atmospheric nitrogen. NO is further oxidized to NO₂ rapidly in air, a process that is facilitated by oxidants such as ozone. Although ozone is primarily an "outside" pollutant, it penetrates indoors. Indoor concentrations of ozone are usually less than 50% of outdoor concentrations, but even small amounts of ozone are important in locations with potential NO₂ sources.¹

NO₂ is the most important and ubiquitous oxide of nitrogen. In high concentrations, NO₂ is an orange-brown gas. Inhaling NO₂ produces an acrid, offensive sensation similar to the sensation experienced when ammonia or chlorine is inhaled.⁵ In lower concentrations, NO₂ appears yellow or invisible and has an odor similar to bleach, but it is less pungent and smells somewhat sweeter than chlorine.⁵ NO₂ is less soluble in water than the gases that are immediately irritating, chlorine and

ammonia. As a result, NO₂ may result in delayed injury without provoking immediate warning symptoms. NO₂ is one of the six “criterion” outdoor air pollutants, but more important for our purposes, it is a major indoor air pollutant.

Sources

The major sources of indoor NO₂ are as follows: (1) Gas stoves and pilot lights (natural gas and propane), (2) wood stoves and fireplaces, (3) gas- and kerosene-fueled space heaters, (4) gasoline engines, and (5) outside air.¹

The amount of indoor air pollution produced depends on the fuel, the design of the stove, and the enclosure design. Other factors are the extent to which the stove is used for heating and the proximity of persons when the stove is in use. It has been demonstrated that even well-tuned space heaters emit CO and NO₂. Malfunctioning or improperly vented space heaters may produce very high levels of both NO₂ and CO. Hedberg et al.⁶ recently reported an outbreak of NO₂-induced respiratory illness among 116 players and spectators at two high school hockey games played at an indoor ice arena. The source of the NO₂ was a malfunctioning engine of the ice resurfacer.

Levels

The national ambient air quality standard for NO₂ is 50 parts per billion (ppb) (or 0.05 parts per million [ppm]) averaged over 1 year. Maximum 30-minute and 24-hour outdoor values of NO₂ can be 0.45 ppm and 0.21 ppm, respectively. In homes with gas stoves, 15 to 25 ppb are added to the usual background level of NO₂.¹ The normal level for such homes ranges from 25 to 75 ppb. Approximately 50% of homes in the United States have gas cooking appliances.¹ In such homes, studies have indicated that peak levels in the kitchen may reach 200 to 1000 ppb.² Peak levels in excess of 2000 ppb, even up to 4000 ppb, have been regularly recorded.⁷ Levels of more than 200 ppm (200,000 ppb) are necessary to immediately endanger life.⁵ Concentrations of 50 to 100 ppm may cause delayed lung injury, such as might occur in silo-filler's disease.⁵

Mechanism of adverse effects

NO₂ is poorly soluble in water and may therefore penetrate to the conducting airways. The primary site of damage after inhalation is the terminal bronchiole and the proximal alveolus.⁸ NO₂ causes effects similar to ozone but requires a much higher concentration. NO₂ causes oxidative damage that results in the generation of free radicals that may oxidize amino acids in tissue proteins. It also initiates lipid peroxidation of polyunsaturated fatty acids in pulmonary cell membranes. NO₂ may adversely affect mucociliary clearance and alveolar macrophage function. With long-term exposure to a two level of 800 ppb, Freeman et al.⁹ demonstrated occasional reduction or even absence of cilia in rats. Alveolar macrophages that were collected after a 3-hour exposure to 0.6 ppm NO₂ tended to inactivate influenza virus in vitro less efficiently than cells collected after air exposure.

Clinical manifestations

NO₂ unquestionably causes lung damage at high concentrations. Exposure to moderate levels (50 ppm) for brief periods may produce cough, hemoptysis, dyspnea, and chest pain.¹¹ Exposure to high concentrations of NO₂ (>100 ppm) can produce pulmonary edema, which can be fatal. The respiratory effects of NO₂ levels currently encountered indoors have been difficult to characterize. Irritation of the eyes, nose, and throat may be the principal health effects of exposure to NO₂ at the levels usually encountered.¹²

The effects of inhalation of NO₂ on pulmonary function in normal subjects have been studied by several investigators, but the results have been inconsistent. For example, Bylin et al.¹³ found that airways resistance increases in healthy subjects at rest after exposure to a low concentration (0.24 ppm) of NO₂ for 20 minutes. Contrast that study to the study of Linn et al.,¹⁴ who found no such change in pulmonary function in subjects who inhaled high concentrations of NO₂ (as high as 4 ppm) for 75 minutes with intermittent exercise. Most clinical studies using a wide range of reasonable exposure conditions have demonstrated minimal effect on pulmonary mechanics or function.¹⁵ It is probably safe to say that in healthy persons clinically relevant effect on pulmonary function are uncommon at the usual indoor NO₂ concentrations.

The effect of NO₂ on susceptible patient populations may be more controversial. In several studies, subjects with mild asthma have generally not responded to exposures as high as 4 ppm for 20 to 120 minutes.⁷ Some studies in asthmatic patients, however, have reported adverse effects of short-term NO₂ exposure below 0.5 ppm.¹⁶ In a study of 11 asthmatic patients, the forced vital capacity (FVC) and peak expiratory flow rate dropped significantly when exposed to 0.3 ppm NO₂ while cooking on a gas stove.¹⁷ The effect of NO₂ in patients with chronic obstructive pulmonary disease (COPD) is likewise unclear. In one study, patients with moderately severe COPD did not show consistent lung function changes with exposures of 0.5, 1.0, and 2.0 ppm for 1 hour.¹⁸ On the other hand, Morrow et al.¹⁹ studied patients with COPD who were exposed to 0.3 ppm NO₂ for 4 hours, during which time the subjects did intermittent light exercise. They found small but significant changes in forced expiratory volume in 1 second (FEV₁) and FVC with NO₂ compared with purified air.¹⁹

The effect of NO₂ exposure on nonspecific bronchial hyperresponsiveness is likewise controversial. In three studies, healthy subjects had unchanged responsiveness after exposures to 0.1,²⁰ 0.48,¹³ and 0.6²¹ ppm. In another study, Mohensin et al.²² exposed 18 healthy subjects to 2.0 ppm NO₂ for 1 hour and were able to demonstrate an increase in methacholine responsiveness.²² Frampton et al.²¹ have shown that continuous exposure of healthy subjects to 1.5 ppm NO₂ for 3 hours resulted

in a greater decrease in FVC and FEV₁ in response to carbachol than after exposure to air.²¹ From these studies one might conclude that, in normal persons, bronchial responsiveness may be affected at concentrations greater than 1.5 to 2.0 ppm.

Asthmatic patients have been considered sensitive to NO₂ since 1976, when Orehek et al.²³ reported that exposure of asthmatic patients to only 0.1 ppm NO₂ for 1 hour increased air reactivity. Since that time, several studies have shown that short-term exposure to low concentrations of NO₂ (0.1 to 0.5 ppm) enhanced airway responsiveness to histamine²⁴ and methacholine²⁵ in at least some of the asthmatic patients studied.²⁶ For example, Bauer et al.²⁷ have recently shown that exposure to NO₂ at low concentrations (0.3 ppm) appears to potentiate exercise-induced bronchospasm.²⁷ In contrast, there have been several studies in asthmatic patients that directly contradict these findings. In these latter studies, asthmatic patients have not shown increased bronchial responsiveness after exposures of from 0.1 to 3.0 ppm for up to 2 hours.⁷

Epidemiologic studies evaluating the association between NO₂ and respiratory symptoms and illness in children have likewise been inconsistent. It should be noted, however, that essentially all studies have reported positive trends.²⁸ In a study of more than 6000 children in the United States, Neas et al.²⁹ found that indoor exposures to NO₂, on the average, were 15 ppb higher in homes with gas stoves and pilot lights. In this group they found increases in individual respiratory symptoms of 5% to 29%. In contrast, a study from the Netherlands found no significant increase in symptoms.³⁰ Braun-Fahrlander et al.²⁸ recently reported a study of 625 Swiss children. They found no association between the NO₂ concentration and incidence of respiratory symptoms but did demonstrate an association with duration of symptoms. A meta-analysis mentioned in a recent review by Gold² that used the epidemiologic literature on indoor exposure to NO₂ at levels produced by gas stoves and heating in households in developed countries suggested a significant but small association between NO₂ and respiratory symptoms in children.

In general, it is probably fair to restate the conclusion from a 1990 American Thoracic Society Workshop summary that the epidemiologic and laboratory evidence for humans has not conclusively demonstrated adverse health effects of NO₂ exposure at the usual indoor concentrations.³¹

Carbon Monoxide

TOP

Chemistry

CO is a colorless, odorless gas that may result from incomplete combustion of any carbonaceous material. Baseline CO levels in the blood are determined by the endogenous production of the gas by the catabolism of hemoglobin and other heme-containing compounds in addition to the intake of low ambient CO levels.

Sources

The major sources of indoor carbon monoxide are as follows: (1) Tobacco smoke, (2) gas stoves and pilot lights, (3) wood stoves and fireplaces, (4) gas- and kerosene-fueled space heaters, (5) gasoline engines, (6) camping lanterns and stoves, and (7) attached garages and street level intake vents.¹

Automobiles are the most prolific sources of CO. In a closed garage lethal concentrations may be achieved in 10 minutes or less.³² A recent report recounted 17 warehouse workers who experienced CO poisoning while working around a propane-fueled forklift in an enclosed warehouse.³³ Numerous cases of CO intoxication in indoor skating rinks have been described in the literature. Most often the victims have been hockey players and the source of the contamination has been the ice resurfacing machine.³⁴

Levels

The Environmental Protection Agency standard is 35 ppm as a 1-hour standard and 9 ppm as an 8-hour standard. The average level in homes without gas stoves is 0.5 to 5 ppm. Hourly CO concentrations during cooking with gas stoves range from 2 to 6 ppm, although 1-hour averages may exceed 12 ppm.¹ Levels of 25 to 50 ppm are common if the gas stove is used for heating.

Traynor et al.³⁵ have reported indoor carbon monoxide levels of 0.4 to 2.8 ppm with the use of newer "airtight" wood burning stoves. In contrast, nonairtight stoves produced average CO levels of 1.8 to 14 ppm.³⁵ During a commute by automobile, CO levels may be 6 to 15 ppm, which is approximately 2 to 5 times the concentrations in homes.¹ At least 5% of each day is spent in transportation. Cigarette smoke contains more than 2% CO, and the average CO concentration that reaches the lung during cigarette smoking is 400 ppm.³⁶ Extremely high levels of CO have been documented in skating rinks, with some levels exceeding 100 ppm.³⁴ CO levels of 2500 ppm are necessary to immediately endanger life.

The normal carboxyhemoglobin level is 0.6%.² Levels up to 2% to 3% may be found in nonsmokers and may be considered within normal limits.³⁷ Levels of 10% to 15% may be recorded immediately after a cigarette is smoked.³⁷ Smoking one pack of cigarettes per day can lead to a chronic daytime carboxyhemoglobin level of 5% to 6%.³⁶ Two to three packs per day may result in a carboxyhemoglobin level of 7% to 9%.³⁶ In a study of hockey players, the average carboxyhemoglobin levels in three different teams after a game was 8.7%, 10.8%, and 13.2%.³⁴ Interestingly, methylene chloride, which is used as a paint stripper, is metabolized in CO. A 3-hour exposure to this substance can result in a carboxyhemoglobin of 16%.³⁶

Mechanism of adverse effects

Adverse effects induced by CO occur through several mechanisms.³⁶ The affinity for hemoglobin is more than 200 times that of molecular oxygen (O₂). CO, therefore, displaces O₂ from binding sites, thus decreasing oxygen carrying capacity. CO also shifts the oxyhemoglobin dissociation curve to the left, thus impairing the release of O₂ to the tissues. CO can also directly impair oxygen diffusion into mitochondria. CO has been shown to interfere with intracellular oxidation and may increase platelet adhesiveness.² The final common pathway is tissue hypoxia.

Clinical manifestations

CO poisoning accounts for more than 3800 accidental and suicidal deaths per year, thus making it the leading cause of death by poisoning. It is estimated that an additional 10,000 persons miss 1 or more days of work as a result of sublethal exposure.³⁷ The effects of higher level exposures such as might occur in a fire or suicide attempt have been well documented (■Table II). The effects of lower level exposures and long-term exposures are less well understood.

TABLE II. Signs and symptoms commonly found in CO intoxication	
Blood level of carboxyhemoglobin (%)	Signs and symptoms
>10%	Headache; impaired vigilance; decreased exercise capacity; angina with coronary artery disease
>20%	Throbbing headache; giddiness; deterioration of judgement, calculation and manual dexterity
>30%	Severe headache; nausea and vomiting; weakness; lethargy
>40%	Tachypnea; tachycardia; obtundation; myocardial injury
>50%	Respiratory failure; coma; convulsions; death

At low levels, CO may produce nonspecific flulike symptoms. Baker et al.³⁸ noted symptoms of headache, lethargy, nausea, or dizziness in children with carboxyhemoglobin levels between 2% to 10%. At carboxyhemoglobin levels of 3% to 4%, an alteration in alertness may be noted.³⁴ Driving skills are impaired at 4%³⁹ and visual acuity may be affected at levels from 5% to 10%.³⁴ Bunnell and Horvath⁴⁰ found that performance of complex tasks was impaired with increasing carboxyhemoglobin levels (0% to 10%) at high work loads.

The effect of low-level CO exposure on cardiac function has been studied. Sheps et al.⁴¹ found that exposure to CO resulting in a carboxyhemoglobin level equal to 6% produced direct effects on the

heart by facilitating ventricular ectopy in patients with coronary artery disease. In another study, Allred et al.⁴² suggested that exposure of patients with coronary artery disease to CO can induce earlier subjective and objective evidence of myocardial ischemia at carboxyhemoglobin levels as low as 2% to 4%.

Carbon Dioxide

[TOP](#)

Chemistry and sources

CO₂ is primarily a by-product of human metabolism and is constantly being emitted into the indoor environment by building occupants. CO₂ may come from combustion sources as well. The major sources of indoor carbon dioxide are as follows: (1) People, (2) kerosene and gas space heaters, (3) tobacco smoke, and (4) outside air.¹

Levels

Outdoor air concentrations normally vary from 320 to 400 ppm.¹² Indoors, complaints of poor air quality are unusual if CO₂ concentrations are less than 700 to 800 ppm.⁴³ In crowded and underventilated rooms, CO₂ levels may rise to 2000 to 5000 ppm.¹²

The adequacy of the supply of fresh air is often assessed by the level of CO₂ in a room. In general, an indoor CO₂ concentration less than 1000 ppm indicates an adequate fresh air supply. Alternatively, the adequacy of ventilation may be measured by the number of cubic feet of air per minute (cfm) provided per person. On average, a CO₂ level of 1000 ppm is equivalent to approximately 15 cubic feet of fresh air per minute per person.⁴³

It is interesting to note that earlier in this century, recommendations for ventilation were designed to provide sufficient fresh air to control body odor during building occupancy. Most indoor air pollution was believed to be of human origin and was measured in OLF units (emission rate of air pollution from a standard person). In actual fact, 15% of indoor air pollution comes from humans and 85% from nonhuman sources.

The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE)⁴⁴ publishes guidelines and standards for the design and operation of building ventilation systems. In the 1930s the standard minimum ventilation rate was 10 to 20 cfm/occupant. As late as 1973, the minimum rate was 20 cfm/occupant. In the 1970s the ASHRAE revised its recommended ventilation standard for fresh air supply to 5 cfm/occupant in response to the energy crisis and oil embargo. Buildings constructed according to these guidelines may not supply enough fresh air. Newly adopted recommendations, ASHRAE standard 62-1989, call for maintaining CO₂ levels at less than 1000 ppm.⁴⁴ A ventilation rate of 15 cfm per person is sufficient to ensure that, under activity levels typical of office environments, the concentration of CO₂ will not exceed 1000 ppm.⁴³ However,

concentrations of CO₂ as low as 700 to 800 ppm are often associated with complaints of poor air quality by occupants.⁴⁵ A CO₂ concentration of 700 ppm would be obtained with a fresh air ventilation rate of 25 cfm per person.⁴³ It is important to note that CO₂ at this level is a marker for poor air exchange rather than a cause of symptoms. To endanger life, levels of 50,000 ppm are necessary.

Mechanism of adverse effects

The mechanism of injury by CO₂ at high concentrations is displacement asphyxia. Oxygen is displaced by the concentration of CO₂ and other gases. The clinical manifestations of such exposures are hyperventilation, diaphoresis, headache, bounding pulse, warm extremities, and, finally, loss of consciousness.

Control of Indoor Air Pollution From Combustion Sources

TOP

The general control options for indoor air pollutants are as follows: (1) Source modification, (2) ventilation of the area, and (3) removal of pollutants from the air.³¹ In modifying the source, one might simply remove the source of the pollution, substitute a less polluting source, or take steps to reduce pollutant emissions from the source. Source modification is the most definitive control method but may not be practical or even feasible. To improve ventilation in and around the source, one might exhaust the pollutant to the outside or away from occupied areas or dilute the concentration of the pollutant by increasing fresh air circulation. To remove pollutants from the air, one might use filtration or gas reactivity. Devices used to remove particles from the air generally operate by mechanical filtration, electrostatic precipitation, or negative ion generation. Gases can be removed by chemical absorption of reactive substances or by physical adsorption onto surfaces.

Conclusion

TOP

This short review has centered on three of the major indoor air pollutants. Each of these substances arise from combustion (and CO₂ from human metabolism). All three have the potential to cause injury, damage, and adverse effects if inhaled in sufficient quantities and concentrations. At levels normally found indoors, clinically significant adverse effects are probably uncommon. Nevertheless, continued awareness of the potential problem is important to avoid circumstances where normal indoor concentrations may reach dangerous levels.

References

TOP

1. Samet JM, Marbury MC, Spengler JD. Health effects and sources of indoor air pollution (Part 1). *Am Rev Respir Dis* 1987;136:1486-508.

MEDLINE

2. Gold DR. Indoor air pollution. Clin Chest Med 1992;13:215-29.

MEDLINE

3. Editorial. Indoor air pollution and acute respiratory infections in children. Lancet 1992;339:396-8.

MEDLINE

4. De Koning HW, Smith KR, Last JM. Biomass fuel consumption and health. Bull World Health Organ 1985;63:11-26.

MEDLINE

5. Douglas WW, Hepper NCG, Colby TV. Silo-filler's disease. Mayo Clin Proc 1989;64:291-304.

MEDLINE

6. Hedberg K, Hedberg CW, Iber C, et al. An outbreak of nitrogen dioxide induced respiratory illness among ice hockey players. JAMA 1989;262:3014-7.

MEDLINE

7. Gong H. Health effects of air pollution. Clin Chest Med 1992;13:201-14.

MEDLINE

8. Chang L, Mercer RR, Stockstill BL, et al. Effects of low levels of NO₂ on terminal bronchial cells and its relative toxicity compared to oxygen. Toxicol Appl Pharmacol 1988;90:451-64.

9. Freeman G, Crane SC, Furiosi NJ, et al. Covert reduction in ventilatory surface in rat during prolonged exposure to subacute nitrogen dioxide. Am Rev Respir Dis 1972;106:563-79.

MEDLINE

10. Frampton FW, Smeglin AM, Roberts NJ, Finkelstein JN, Morrow PE, Utell MJ. Nitrogen dioxide exposure in vivo and human alveolar macrophage inactivation of influenza virus in vitro. Environ Res 1989;48:179-92.

MEDLINE

11. Rosenstock L. Occupational medicine: state of the art reviews. Philadelphia: Hanley & Belfus, 1987:303-5.

12. Fernandez-Caldas E, Fox RW. Environmental control of air pollution. Med Clin North Am 1992;76:935-52.

MEDLINE

13. Bylin G, Lindvall T, Rehr T, Sundin B. Effects of short term exposure to ambient nitrogen dioxide concentrations on human bronchial reactivity and lung function. Eur Respir

Dis 1985;66:205-17.

14. Linn WS, Shamoo DA, Avol EL, et al. Dose-response study of asthmatic volunteers exposed to nitrogen dioxide during intermittent exercise. Arch Environ Health 1986;41:292-6.

MEDLINE

15. Samet JM, Utell MJ. The risk of nitrogen dioxide: what have we learned from epidemiological and clinical studies? Toxicol Industrial Health 1990;6:247-62.

16. Roger LJ, Horstman DH, McDonnell WF, et al. Pulmonary effects in asthmatics exposed to 0.3 ppm NO₂ during repeated exercise. Toxicologist 1985;5:70.

17. Goldstein IF, Leiber K, Andrews LR, et al. Acute respiratory effects of short-term exposures to nitrogen dioxide. Arch Environ Health 1988;43:138-42.

MEDLINE

18. Linn WS, Shamoo DA, Spier CE, et al. Controlled exposure of volunteers with chronic obstructive pulmonary disease to nitrogen dioxide. Arch Environ Health 1985;40:313.

MEDLINE

19. Morrow PE, Utell MJ, Bauer MA, et al. Pulmonary performance of elderly normal subjects and subjects with chronic obstructive pulmonary disease exposed to 0.3 ppm nitrogen dioxide. Am Rev Respir Dis 1992;145:291-300.

MEDLINE

20. Hazucha MJ, Ginsberg JF, McDonnell WF, et al. Effects of 0.1 ppm nitrogen dioxide on airways of normal and asthmatic subjects. J Appl Physiol 1983;54:730-9.

MEDLINE

21. Frampton MW, Morrow PE, Cox C, Cobb FR, Speers DM, Utell MJ. Effects of nitrogen dioxide exposure on pulmonary function and airway reactivity in normal humans. Am Rev Respir Dis 1991;143:522-7.

MEDLINE

22. Mohensin V. Airway responses to 2.0 ppm nitrogen dioxide in normal subjects. Arch Environ Health 1988;43:242-6.

MEDLINE

23. Orehek J, Massari JP, Gayraud P, Grimaud C, Charpin J. Effects of short-term, low-level nitrogen dioxide exposure on bronchial sensitivity of asthmatic patients. J Clin Invest 1976;57:301-7.

MEDLINE

24. Bylin G, Hedensteirna G, Lindvall T, Sundin B. Ambient nitrogen dioxide concentrations increase bronchial responsiveness in subjects with mild asthma. Eur Respir J 1988;1:606-

12.

MEDLINE

25. Kleinman MT, Baily RM, Linn WS, et al. Effect of 0.2 ppm nitrogen dioxide on pulmonary function and response to bronchoprovocation in asthmatics. *J Toxicol Environ Health* 1983;12:815-26.

MEDLINE

26. Magnussen H. Experimental exposure to nitrogen dioxide. *Eur Respir J* 1992;5:1040-2.

MEDLINE

27. Bauer MA, Utell MJ, Morrow PE, Speers DM, Gibb FR. 0.30 ppm nitrogen dioxide inhalation potentiates exercise induced bronchospasm in asthmatics. *Am Rev Respir Dis* 1984;129:A151.

28. Braun-Fahrlander C, Ackermann-Liebrich U, Schwartz J, et al. Air pollution and respiratory symptoms in preschool children. *Am Rev Respir Dis* 1992;145:42-7.

MEDLINE

29. Neas LM, Dockery DW, Ware JH, et al. Association of indoor nitrogen dioxide with respiratory symptoms and pulmonary function in children. *Am J Epidemiol* 1991;134:204-19.

MEDLINE

30. Brunekreef B, Fischer P, Houthuijs D, et al. Health effects of indoor NO₂ pollution: In: *Proceedings of the fourth International Conference on Indoor Air Quality and Climate*, vol 1. Berlin: Federal Republic of Germany Institute for Water, Soil, and Air Hygiene, 1987:304.

31. Samet J. Environmental controls and lung disease. *Am Rev Respir Dis* 1990;142:915-39.

MEDLINE

32. Meredith TJ, Vale JA. Carbon monoxide poisoning. *Br Med J* 1988;296:77-9.

33. Fawcett TA, Moon RE, Fracica PJ, Mebane GY, Theil DR, Piantadosi CA. Warehouse workers' headache: carbon monoxide poisoning from propane-fueled forklifts. *J Occup Med* 1992;34:12-5.

MEDLINE

34. Levesque B, Dewailly E, Lavoie R, Prud'homme D, Allaire S. Carbon monoxide in indoor ice skating rinks: evaluation of absorption by adult hockey players. *Am J Public Health* 1990;80:594-8.

MEDLINE

35. Traynor GW, Apte MG, Carruthers AR, Dillworth JF, Grimsrud DT, Gundel LA. Indoor air pollution due to emissions from wood burning stoves. *Environ Sci Technol* 1987;21:691-7.

36. Beard RR. Inorganic compounds of oxygen nitrogen and carbon. In: Patty's industrial hygiene and toxicology. New York: John Wiley & Sons, 1982.

37. Ilano AL, Raffin TA. Management of carbon monoxide poisoning. Chest 1990;97:165-9.

MEDLINE

38. Baker MD, Henretig FM, Ludwig S. Carboxyhemoglobin levels in children with nonspecific flu-like symptoms. J Pediatr 1988;113:501-4.

MEDLINE

39. Wright G, Randall P, Shepard RJ. Carbon monoxide and driving skills. Arch Environ Health 1973;27:349-54.

MEDLINE

40. Bunnell DE, Horvath SM. Interactive effects of physical work and carbon monoxide on cognitive task performance. Aviat Space Environ Med 1988;59:1133-8.

MEDLINE

41. Sheps DS, Herbst MC, Hinderliter AL, et al. Production of arrhythmias by elevated carboxyhemoglobin in patients with coronary artery disease. Ann Intern Med 1990;113:343-51.

MEDLINE

42. Allred EN, Bleacher ER, Chaitman BR, et al. Short term effects of carbon monoxide exposure on the exercise performance of subjects with coronary artery disease. New Engl J Med 1989;311:406-12.

43. Ellenbecker MJ. Engineering controls for clean air in the office environment. Clin Chest Med 1992;13:193-9.

MEDLINE

44. American Society of Heating, Refrigerating, and Air Conditioning Engineers. Ventilation for acceptable indoor air quality, ASHRAE standard 62-1989. Atlanta: American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1989.

45. Burgess WA, Ellenbecker MJ, Treitman RD. Ventilation for control of the work environment. New York: John Wiley & Sons, 1989.

46. Samet J, Marbury MC, Spengler JD. Health effects and sources of indoor air pollution (Part 2). Am Rev Respir Dis 1988;137:221-42.

MEDLINE

- *From the Division of Pulmonary, Critical Care, and Occupational Medicine, Department of Internal Medicine, University of South Florida College of Medicine, and the Department of Environmental and Occupational Health, University of South Florida College of Public Health.*
- *Reprint requests: W. Michael Alberts, MD, Pulmonary, Critical Care and Occupational Medicine, 13000 Bruce B. Downs Blvd. (111C), Tampa, FL 33612. J ALLERGY CLIN IMMUNOL 1994;94:289-95.*
- *Copyright © 1994 by Mosby–Year Book, Inc.*
- *0091-6749/94 \$3.00 + 0 1/0/56007*