# Nitrogen Dioxide Exposures inside Ice Skating Rinks

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ABSTRACT

*Objectives.* The common operation of fuel-powered resurfacing equipment in enclosed ice skating rinks has the potential for producing high concentrations of carbon monoxide and nitrogen dioxide. Exposures to these gaseous combustion products may adversely affect the health of those inside the rink. Little information is available on pollutant concentrations under normal operating conditions.

*Methods.* One-week average nitrogen dioxide concentrations in 70 northeastern US rinks were measured with passive samplers during normal winter season conditions.

*Results.* The median nitrogen dioxide level inside rinks was 180 ppb, more than 10 times higher than the median outdoor concentration. One-week average nitrogen dioxide concentrations above 1000 ppb were measured in 10% of the rinks.

*Conclusions.* Considering that short-term peak concentrations were likely to have reached two to five times the measured 1-week averages, our results suggest that nitrogen dioxide levels were well above short-term air quality guidelines and constitute a public health concern of considerable magnitude. (*Am J Public Health.* 1994;84:429–433)

## Introduction

In skating rinks, the operation of gasoline- or propane-powered equipment to clean and resurface the ice can lead to elevated concentrations of combustion products. Reports indicate that high concentrations of carbon monoxide in ice rinks occasionally lead to toxicity.[1–6] Recently, acute respiratory illness due to nitrogen dioxide exposure has also been reported at indoor ice rinks.[7–11]

Acute exposure to nitrogen dioxide concentrations above 5 to 10 parts per million (ppm) may produce severe cough, hemoptysis, chest pain, and pulmonary edema.[12–14] The effects of exposure to lower levels (0.1 to 1 ppm), such as those encountered in homes using gas stoves or kerosene heaters, are more debatable. Controlled exposures of healthy (nonasthmatic) individuals to nitrogen dioxide concentrations above 1000 parts per billion (ppb) (exposure for 1 hour or longer) indicate increased airway responsiveness,[15–17] whereas exposures to lower levels have not produced any effects. On the other hand, controlled chamber studies with asthmatics suggest that small changes occur in spirometric measures and airway responsiveness for short-duration exposures to 100 to 500 ppb nitrogen dioxide.[15,18,19] However, other studies have shown no respiratory effects in asthmatics following exposures to higher levels.[20,21] Consequently, asthmatics are considered to be especially susceptible to respiratory effects of nitrogen dioxide exposure.

Because controlled chamber studies have involved mostly adult subjects, epidemiological studies may have more relevance to the ice skating population since they investigated children. Neas and colleagues report an odds ratio of 1.45 for lower respiratory symptoms in children for an increase in the annual average nitrogen dioxide concentration of 15 ppb.[22] A recent meta-analysis of 11 epidemiological studies yielded similar results, suggesting a 20% increase in the odds of a lower respiratory infection for children with a prolonged increase in exposure to 16 ppb nitrogen dioxide.[23]

Although occurrences are infrequent and are typically associated with resurfacer malfunction, which produces peak nitrogen dioxide concentrations of 1000 to 3000 ppb, reports of acute nitrogen dioxide poisoning in ice rinks demonstrate that an acute exposure in this setting can lead to respiratory illness. In contrast, we sought to examine the potential public health impact of repeated exposures to nitrogen dioxide by investigating the range of concentrations encountered in skating rinks under normal operating conditions. We hypothesized that ice rinks presented the major nitrogen dioxide exposure of users and that, based on comparisons with epidemiological studies of indoor exposures, levels of nitrogen dioxide encountered in ice rinks warrant concern.

## Methods

A mail-in survey was conducted in spring 1990. One hundred seven rinks

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**TABLE 1—Measured Nitrogen Dioxide Concentrations in Enclosed Rinks**

| Location of Sampler | No. | Geometric Mean, ppb | Geometric SD | Range, ppb |
|---|---|---|---|---|
| Outdoors | 54 | 17.6 | 2.4 | 0.44–193 |
| Resurfacer | 57 | 128.0 | 3.6 | 3.11–1428 |
| Bench | 57 | 169.0 | 4.0 | 3.11–2140 |
| Rink sample 2 | 53 | 168.0 | 4.0 | 1.76–2470 |

were contacted and asked to deploy passive nitrogen dioxide sampling devices and to complete a questionnaire. Sampling tubes, instructions, and questionnaires were mailed to all participants, and follow-up contact was made by phone. Strict criteria on sample placement and handling were described: all samplers were to be deployed for the same 7-day duration at all rinks, with at least one sampler placed immediately outside the rink but away from parking lots and major traffic areas (outdoors), one sampler placed on the main resurfacer (resurfacer), one sampler placed at the scorekeeper's bench as close to breathing height as possible (bench), and one sampler placed at the opposite side of the rink from the scorekeeper's table (rink sample 2). Additionally, each sampling packet contained either a field blank or a duplicate sampler to be placed at one of the four designated sites along with the primary sampler. Nitrogen dioxide concentrations were measured with Palmes tubes diffusive samplers, which provide an integrated average of the nitrogen dioxide concentration over a defined sampling interval.[24–26] Following the sampling period, participants returned the sampling tubes to our laboratory for analysis.

Along with the sampling tubes, participants returned a completed questionnaire describing the use of the rink and resurfacing equipment, the physical characteristics of the rink, and the building's ventilation. Questions regarding rink age and seating capacity were asked for their potential use as surrogate data for building air tightness and volume, respectively. Except where indicated, the scorekeeper's bench sample was used to measure the indoor concentration of the rink. Additionally, open-air rinks were excluded from the analysis except where specifically stated. Relationships between nitrogen dioxide concentrations and rink variables obtained from questionnaires were examined by viewing scatter plots of concentration data, log-transformed concentration data, and single-factor analysis of variance of log-transformed concentration data.

## *Results*

Valid samples and questionnaires were obtained from 70 of the 107 (65%) rinks contacted for the survey, a response rate that is in good agreement with other mail-in air pollution surveys.[27,28] Literature reports[8] and discussions with industry representatives indicate that there are more than 2000 operating ice rinks in North America. While the 70 rinks included in our survey were not intended to constitute a random representative sample, they do represent a significant proportion of operating rinks in New England.

Summary statistics of nitrogen dioxide concentrations are presented in Table 1. Samples of outdoor concentrations were substantially lower than any of the other samples for all rinks but one, with the median indoor concentration amounting to approximately 10 times the median outdoor level. Indoor concentrations from both samples in each rink were similar, indiating that nitrogen dioxide concentrations were quite homogeneous near the ice surface. Rink samples were also higher than the sample collected on the resurfacer, owing to the storage of the resurfacer either outdoors or in a garage when not in use. The resurfacer concentrations of nitrogen dioxide therefore should not be interpreted as a measure of resurfacer operator exposure.

Significant differences ($P < .05$) in nitrogen dioxide concentrations were observed between enclosed (geometric mean = 169.5 ppb; geometric standard deviation [SD] = 4.0; n = 58) and open rinks (geometric mean = 16.2 ppb; geometric SD = 1.57; n = 9), with greater differences observed if the enclosed rink did not have a ventilation system. Nitrogen dioxide concentrations in enclosed rinks without ventilation systems (geometric mean = 329.7 ppb; geometric SD = 3.7; n = 7) were higher than those in rinks with ventilation systems (geometric mean = 154.7 ppb; geometric SD = 4.0; n = 51), although the difference was not significant. The presence of a ventilation system in a rink does not necessarily mean that the system was in operation or was being operated at full capacity.

Although trends were evident, no other statistically significant differences in nitrogen dioxide concentrations were observed. Higher nitrogen dioxide concentrations were measured in rinks with propane-fueled resurfacers (geometric mean = 221.1 ppb; geometric SD = 3.3; n = 27) than in rinks using gasoline-powered resurfacers (geometric mean = 134.0 ppb; geometric SD = 4.6; n = 31); such a finding was expected because of the lower combustion temperature of propane relative to gasoline and the consequent increase in nitrogen dioxide emissions. None of the rinks tested used diesel- or electric-powered resurfacers, although these are commercially available. The presence of catalytic converters was distributed evenly between the two fuel types of resurfacers; rinks with a resurfacer containing a catalytic converter had higher nitrogen dioxide levels (geometric mean = 214.0 ppb; geometric SD = 3.3; n = 25) than rinks with a resurfacer that lacked a catalytic converter (geometric mean = 140.0 ppb; geometric SD = 4.3; n = 31). This result is explained by the oxidative properties of the catalyst, which is designed to convert carbon monoxide to carbon dioxide. Ninety-two percent of rinks used a resurfacer with a four-cylinder engine; 7% used an eight-cylinder model, and one rink used a six-cylinder model.

Rink size, as measured by seating capacity, was not a significant determinant of nitrogen dioxide concentration. This may be owing to inadequate air mixing in rinks, such that the effective volume of elevated nitrogen dioxide is smaller than the total rink volume. This is possible given the temperature stratification within enclosed rinks,[1] where cool air near the ice surface prevents effective mixing of the combustion emissions with the warmer air above. Thus, seating capacity may be a poor surrogate for rink volume. The number of resurfacings per day also was not a significant predictor of nitrogen dioxide concentration, although this was probably owing to the low sample sizes of rinks with fewer than 10 or more than 13 resurfacings per day.

Table 2 summarizes the rink characteristics.

## *Discussion*

To estimate the importance of nitrogen dioxide exposures in ice rinks, we compared our measurements with those from other environments. Typical ambient nitrogen dioxide concentrations in urban areas are below 50 ppb, with infrequent hourly values above 200 ppb. Indoor concentrations are often much higher than ambient values, particularly in homes with unvented gas appliances. Since more than 40% of US homes contain gas appliances, the problem of elevated indoor nitrogen dioxide is more widespread. Extensive (2-week average) measurements in Boston homes with gas stoves[29] report median concentrations of 20 to 40 ppb, depending on the season of the measurement and the location in the home where the measurement was collected. Ninety-ninth-percentile values of approximately 100 ppb were recorded for kitchen measurements in all seasons except summer. During cooking, peak nitrogen dioxide concentrations of 450 ppb (1-hour average) are sustained for 1 to 2 hours.[30] This scenario of short-duration intermittent exposures is similar to the 1- to 3-hour exposures experienced by spectators and skaters in ice rinks; rink employees as well as coaches and figure skaters are likely to be exposed for longer periods (4 to 8 hours). Skaters are probably the most susceptible to health effects of air pollutants in an ice skating rink since ventilation rates while skating are expected to exceed normal resting breathing rates by three to five times.[4]

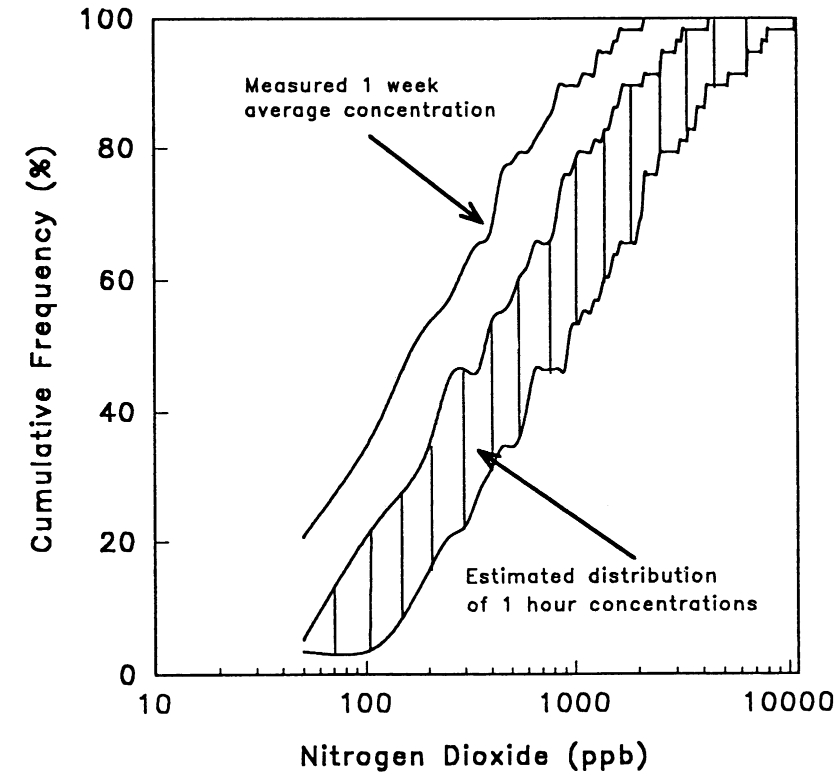
The detailed study by Lee and colleagues[31] adds insight into the peak nitrogen dioxide concentrations produced inside ice rinks. If the temporal distribution of nitrogen dioxide and carbon monoxide concentrations in ice rinks are similar, we estimate that 1-hour nitrogen dioxide concentrations would be two to five times the measured 1-week average (Figure 1). Assuming that the parameters assessed in our survey are typical of the more than 2000 ice rinks in operation in the United States and Canada, a rink is staffed by employees for 14 hours and visited by 300 people (for 1 to 2 hours) daily (Table 2). Therefore, 500 000 or more individuals per day may be exposed to concentrations of nitrogen dioxide that are well above the highest measured ambient and indoor levels. Repeated exposures are common, since high school and college hockey teams practice daily from September to April and recreational players skate once or twice weekly. The high levels of nitrogen dioxide encountered in ice skating rinks present an extreme exposure not likely to be encountered in other indoor, ambient, or occupational settings.

Measurements of carbon monoxide and nitrogen dioxide collected after serious poisoning incidents indicate that levels probably exceeded even ceiling limits for occupational conditions.[32] From a regulatory standpoint, then, it is most important to eliminate incidents through corrective action and to set air quality standards for normal operating conditions at levels well below those that lead

**TABLE 2—Ice Rink and Resurfacer Use Characteristics, All Rinks**

| | Mean | SD | Range |
|---|---|---|---|
| Seating capacity | 1228 | 1461 | 0–7800 |
| Rink age, y | 20 | 13 | 1–86 |
| Rink use, h/d | 14 | 3.4 | 7–20 |
| Users per day | 352 | 218 | 75–1000 |
| Resurfacer use, min/wk | 740 | 227 | 168–1260 |
| Tuneups per year | 6 | 8 | 1–52 |
| Edger use, min/wk | 104 | 420 | 5–420 |

*Note.* Numbers listed are for typical weekdays. In many rinks, weekend user numbers increase to two to five times the weekday numbers.




*Note.* Distribution of 1-hour concentrations is based on peak levels, which are two to five times higher than the measured 1-week average.

**FIGURE 1—Cumulative frequency distribution of measured (1 week average) and estimated short-term peak (1 hour average) nitrogen dioxide concentrations in enclosed ice skating rinks.**

to measurable acute effects. Minnesota has enacted air quality standards for ice arenas[33,34] stipulating that immediate corrective action must be taken when carbon monoxide exceeds 34 ppm or nitrogen dioxide exceeds 0.5 ppm (1-hour average) and requiring rinks to be evacuated when carbon monoxide exceeds 125 ppm or nitrogen dioxide exceeds 2 ppm. This standard protects against accidents where immediately dangerous levels of pollutants are present, but it is insufficient to provide a margin of safety to protect susceptible subgroups, such as asthmatics or children.

Although policy for indoor air quality has not yet been developed by the US government, short-term guidelines (1-hour average) of 200 ppb and 250 ppb nitrogen dioxide have been published for residential indoor air by the World Health Organization (WHO)[35] and the Department of National Health and Welfare Canada,[36] respectively. These guidelines are designed to protect sensitive members of the population (such as asthmatics) with an adequate margin of safety. Although these guidelines are more pertinent to ice rinks than are ambient air standards, they were developed primarily for residential environments and therefore have only limited applicability for indoor ice arenas. Moreover, because skaters are often young children, occupational standards based on a healthy adult worker are not appropriate.

Figure 1 indicates that at least 60% of the rinks included in this survey would exceed the 1-hour WHO limit of 200 ppb or the Canadian guideline of 250 ppb. In fact, it may be premature to emphasize an air quality standard for ice rinks when so many rinks are likely to be out of compliance. Instead, efforts should be directed toward education, design, and operational changes in order to mitigate the impact of resurfacers on air quality.

Strategies to maintain 1-hour nitrogen dioxide and carbon monoxide concentrations below 250 ppb and 35 ppm, respectively, are recommended. For example, warming the resurfacer engine with the exhaust vented outside will reduce indoor concentrations of carbon monoxide; however, this strategy is not effective for reducing nitrogen dioxide emissions. For many enclosed rinks, preventing short-term nitrogen dioxide levels from exceeding 250 ppb (1-hour average) will require increased ventilation and/or reduced use of resurfacing equipment. During a typical 11-minute resurfacing operation using a well-maintained resurfacer, approximately 5 L of nitrogen dioxide are released (Appendix). This volume of nitrogen dioxide would have to be diluted with 20 000 $m^3$ of clean air to achieve a concentration of 250 ppb. With hourly resurfacings, a typical rink building of 22 000-$m^3$ volume would require nearly one air exchange per hour or 13 000 cu ft of ventilation air per minute. Furthermore, mechanical ventilation systems must be designed so that the cooler air over the ice surface, which contains the highest concentrations of nitrogen dioxide, mixes adequately.

Depending on the location of the rink, additional heating of the ventilation air may be required. Across the region where most of the ice skating rinks are found (throughout Canada, the midwestern United States, and New England), heating degree-days range from 5000 to 10 000. Since indoor temperatures for ice rinks tend to be in the low 40s (°F), we used 5000 degree-days to compute the additional energy required for a rink building to achieve one air exchange per hour. For example, a gas-fueled heater with a heat exchanger at a fuel price of $0.005/cu ft would cost $6000 to $8000 annually to operate. For the approximately 50% of rinks that operate for the entire year, providing chilled dehumidified air in the summer could more than double these energy costs. Since our survey found that 10% of the enclosed rinks do not even have a ventilation system, certain rinks would also need to incur large capital costs to achieve desirable air quality.

An alternative approach is to replace existing gasoline- or propane-fueled resurfacers with electrically powered units. Since resurfacers typically have operating lifetimes of 20 to 30 years and cost $60 000 to $70 000, replacement of existing resurfacers is equivalent to an annual cost of approximately $3000.

This paper, along with reports on outbreaks of illness, points to the potential seriousness of exposures to air pollutants in ice rinks. Public health officials should recognize that inadequate ventilation and poor maintenance of the resurfacer can result in nitrogen dioxide and carbon monoxide levels that are injurious to normal healthy individuals. However, even when equipment is properly maintained, inadequate ventilation will result in nitrogen dioxide levels that can evoke airway responses in asthmatics. Health agencies are encouraged to enact requirements to prevent potentially deleterious exposures in enclosed ice skating arenas. □

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## APPENDIX—Estimation of Nitrogen Dioxide Emission Rate

The average carbon monoxide emission rate as measured by Lee et al.[31] was 9 L $min^{-1}$. During measurements, there were 14 resurfacings lasting 10 minutes each; these resulted in a total emission of 1260 L of carbon monoxide, emitted into a rink building with a volume of 20 000 $m^3$, with an air exchange rate of 0.2 $hr^{-1}$. The resulting concentration of carbon monoxide was 13 ppm.

During this same period, 700 ppb of nitrogen dioxide were measured. Assuming that carbon monoxide and nitrogen dioxide have the same emission and concentration profile, the measured concentration of 700 ppb nitrogen dioxide corresponds to a total emission volume of 68 L nitrogen dioxide and an emission rate of approximately 0.5 L $min^{-1}$ nitrogen dioxide. This estimated emission rate is likely to be an underestimate of the true nitrogen dioxide emission rate since this calculation assumes that carbon monoxide and nitrogen dioxide have identical decay rates when, in fact, nitrogen dioxide is likely to decay significantly faster than carbon monoxide.