Public Health
Carbon Monoxide Exposure in Indoor Ice Arenas

By Ron Dobos

In Brief
- Carbon monoxide (CO) poisoning in indoor skating rinks has been recurring since the 1960s. Nitrogen dioxide (NO_2), another potentially hazardous combustion product, also may be present at harmful levels.
- Fossil-fuel-powered ice resurfacing machines and lack of adequate ventilation results in high levels of CO and NO_2, which can adversely affect skaters in indoor ice arenas.
- Electric ice resurfacing equipment significantly lowers CO and NO_2 exposures in ice arenas.
- Regular maintenance on ice resurfacing machines, exhaust ventilation for equipment, outdoor air ventilation with good air distribution inside arenas, measuring CO and NO_2 levels daily, and allocating resources to train staff and maintain equipment can reduce CO and NO_2 levels in ice arenas.

Carbon monoxide (CO) and nitrogen dioxide (NO_2) exposures often recur among recreational ice arena users. This article primarily focuses on CO exposures, since much of the research for indoor ice arenas has been done on it and the health effects are more pronounced.

Although more than one source of CO and NO_2 may exist or be present inside ice arenas, the most common source of these contaminants is the exhaust from combustion of fossil fuels (e.g., gasoline, propane, diesel) in ice resurfacing and edging machine engines. Exposure to high concentrations of CO and NO_2, particularly among children during exercise, can lead to acute and chronic illness (Pelham, Holt & Moss, 2002). Since the 1970s, results of epidemiological, environmental and clinical investigations involving adverse health effects from poor indoor air quality in indoor ice rinks have been published (Pelham, et al.).

"The first recorded episode of illness among children skating in a Minnesota ice arena occurred in 1966 when girls aged 7 to 11 developed headaches and nausea while figure skating" (Minnesota Dept. of Health, 2012). As recently as December 2011, 23 children were treated and four hospitalized following CO exposure in a Florida ice arena (Zimmer, 2011).

Despite the attention received by public exposures to CO, the population that is perhaps most at risk for recurring exposures and acute and cumulative health effects are ice rink employees, especially ice resurfacing machine operators. Ice resurfacing machine operators' exposures (Table 1) can range from 21 to more than 200 ppm (averaged over a 5-minute period). The average exposure during resurfacing was 73 ppm (Anderson, 1971; Lofgren, 2002).

In 1984, Colorado's Pitkin County Health Department measured CO in an indoor ice rink and achieved an 8-hour time weighted average (TWA) concentration of 53.8 ppm and a 1-hour reading of 80.5 ppm. NIOSH investigators analyzed the exhaled air of eight rink workers in the Pitkin County rink and results indicated carboxyhemoglobin (COHb) levels of 5.7%. Even though exposure limits are based on maintaining COHb levels between 2% and 3.5%, none of the workers registered any health complaints (CDC, 1986).

OSHA citations for CO exposure in ice arenas from 2002 to 2012 were not identified during research for this article. This may be attributable to the small number of rink workers and the nature of CO exposures at levels that are potentially harmful when chronic, but that may not manifest as acute illness. CO is odorless and colorless, and workers may simply accept the ice resurfacing machine exhaust as a normal and unavoidable nuisance. Additionally, rink workers spend time in all areas of the ice arena and do not spend as much time on the ice surface (where higher levels of CO accumulate) in vigorous activity like skaters do. If OSHA conducts a site inspection

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related to complaints, inspectors arrive after the fact and accurate levels of CO cannot be obtained because the concentrations have dissipated or been diluted. OSHA will not issue citations from exhaled air analysis of COHb (OSHA Archive, 1991). Furthermore, OSHA only has jurisdiction over workers. It does not cite employers based on public exposures.

The unique properties of indoor ice arenas may encourage high levels of CO and other contaminants. Yang, Chen, Demokritou, et al. (1996), showed that due to the configuration of the ice rink (surrounded by boards and Plexiglas) and the cold temperature near the ice surface, little fresh air can reach the ice surface. This causes the highest concentrations of CO to remain close to the ice surface during and after resurfacing machines are used.

Usually, the resurfacer is used every 30 minutes to an hour (approximately eight times per weekday and 16 times per weekend). A typical ice arena can be resurfaced in about 15 to 20 minutes (Yang, et al., 1996).

Ice resurfacing machines shave a thin layer of ice as screw conveyors rotate above the blade to remove the shavings. The shavings are collected in a large bin (snow tank). Meanwhile, jets of water clean the ice by flushing dirt and debris from the remaining grooves in the ice into a vacuum hose. Finally, a towel spreads the ice-making water (usually warm water) which sprays out of holes in the back of the machine, leaving behind a smooth sheet of ice (Zamboni Co., 2012).

The operating temperature of the ice resurfacing machine engine determines the emissions of CO and NO_2. When the engine is first started, it runs at lower than ideal temperature, running "lean." This causes the fuel-to-air mixture to be too low to provide optimal combustion, increasing CO emissions. As the engine reaches optimal operating temperature, CO emissions drop. Further use of the engine causes it to run hot or overheat. This causes increased NO_2 emissions (Boettern, 2000).

Exposure Limits

Occupational exposure limits (OELs) have been established for CO and NO_2 by regulatory and advisory agencies (Table 1). OELs are based on an 8- to 10-hour TWA exposure and a 40-hour workweek. The established limits "represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, over a working lifetime, without adverse health effects" (ACGIH, 2010). OELs only apply to workers and, therefore, are not enforceable when applied to nonemployees of an ice arena, such as patrons, skaters and spectators. The OELs can be useful when evaluating reports of symptoms from ice arena occupants that may be attributable to CO or NO_2 exposures.

For the general public, air quality guidelines for CO and NO_2 have been established by EPA, World Health Organization (WHO) and Canadian Environmental Protection Act (Table 2).

EPA provides exposure limits for a limited number of substances for the general population and the outdoor environment, known as National Ambient Air Quality Standards (NAAQS). These limits are often applied by professionals to the indoor nonindustrial environment with the thought that the indoor air quality should not be worse than the outdoor air quality.

Table 1

CO & NO_2 Occupational Exposure Limits

	Exposure limit
CO	
OSHA-PEL TWA	50 ppm
ACGIH-TLV TWA	25 ppm
NIOSH-REL TWA	35 ppm, 200 ppm ceiling
NIOSH-IDHL	1,200 ppm
NO_2	
OSHA-PEL	5 ppm
ACGIH-TLV TWA	3 ppm, 5 ppm STEL
NIOSH-REL	1 ppm
NIOSH-IDHL	20 ppm

Table 2

CO & NO_2 General Public Ambient Air Concentrations

	CO		NO_2	
	1-hr average	8-hr average	1-hr average	8-hr average
EPA	35 ppm	9ppm	--	--
WHO	26 ppm	9ppm	0.1 ppm	--
Canadian Environmental Protection Act (CEPA): maximum acceptable level (provides adequate protection)	31 ppm	13 ppm	--	--
CEPA: maximum desirable level (long-term goal)	13 ppm	5 ppm	0.213 ppm	--
CEPA: maximum tolerable level (action required to lower level)	--	17 ppm	0.532 pm	

Keywords

OSHA-PEL: OSHA permissible exposure limit.
ACGIH-TLV: American Conference of Governmental Industrial Hygienists threshold limit value.
NIOSH-REL: NIOSH recommended exposure limit.
TWA: Time-weighted average. The exposure concentration for a conventional 8-hr workday (or up to a 10-hour workday for the REL) and a 40-hr workweek.
Ceiling: The concentration that shall not be exceeded during any part of the working exposure.
STEL: Short-term exposure limit. Usually a 15-minute TWA exposure that should not be exceeded at any time during a workday, even if the 8-hr TWA is within established limits.
IDLH: Immediately dangerous to life and health. An exposure that is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment (CDC, 1994).

WHO has updated its recommended CO exposure limits in order to keep COHb levels from exceeding 2.5%, even when a normal subject engages in light or moderate exercise (WHO, 1999).

Canadian National Ambient Air Quality Objectives (NAAQOs) for CO (maximum acceptable level) have been set to maintain COHb levels less than 2%.

WHO's NO_2 limit is set as an annual average (0.04 ppm) which is similar to EPA's NAAQS (0.053 ppm) and Canada's NAAQO (0.053 ppm). The annual average is not applicable to the indoor environment. WHO has established a 1-hour average for NO_2 that may be applied to the indoor nonindustrial environment. Canada has also established a 1-hour maximum desirable level (long-term goal) for NO_2 and a 1-hour maximum tolerable level (actions required to lower levels) (Table 2, p. 39).

Health Effects

When an individual is exposed to CO, approximately 80% to 90% of the absorbed CO binds with hemoglobin, resulting in a reduction in the oxygen-carrying capacity of the blood (ACGIH, 2001). Symptoms of acute CO exposure may include headache, nausea, vomiting, altered vision and shortness of breath. Chronic exposure may result in lack of blood flow to the heart, arrhythmia, heart attack and angina (Pelham, et al., 2002).

Acute NO_2 exposure can result in eye, nose, throat and respiratory tract irritations, shortness of breath and pulmonary edema. Low-level exposure can result in bronchial reactivity in asthmatics, decreased lung function in those with chronic obstructive pulmonary disease and risk of respiratory infections. Chronic exposures can lead to chronic bronchitis (EPA, 2012).

The American Conference of Governmental Industrial Hygienists threshold limit value (ACGIH-TLV) of 25 ppm for CO has been established to maintain blood COHb levels below 3.5%, to minimize the potential for headache, nausea and altered vision, and to maintain cardiovascular work and exercise capacities, in "normally healthy adults" (ACGIH, 2001).

Similarly, WHO states that cardiovascular symptoms can result from COHb levels of 3% (WHO, 2011). Levesque, Dewailly, Lavoie, et al. (1990), indicate that COHb levels of 3% to 4% result in alteration of alertness and arterial dilation in response to a drop in blood oxygenation, and can worsen symptoms of people with existing heart problems.

The goal of limiting CO exposure in breathing air is to minimize adverse health effects in most individuals by controlling the amount of CO that displaces oxygen in the blood. COHb levels in the range of 2.5% to 3.5% are generally accepted as below the threshold for causing symptoms (ACGIH, 2001; WHO, 1999). For comparison, note that in healthy nonsmoking adults, baseline levels of COHb are about 1% and in smokers the average COHb levels are about 5% (ACGIH, 2001).

While performing sedentary work with an atmospheric CO concentration of 50 ppm, it takes 191 minutes to reach a 3.5% COHb. With moderate work, it only takes 87 minutes (ACGIH, 2001). To help visualize how a typical hockey player may approach 3.5% COHb, consider that the approximate duration of a recreational league hockey game is about 90 minutes. CO levels have been measured as high as 304 ppm during propane-fueled resurfacing and the CO concentrations at ice level remain high for at least 30 minutes after resurfacing (Johnson, Moran, Paine, et al., 1975).

Children have a higher rate of metabolism than adults, thus, children have a higher uptake of CO. In addition, the activity of skating may increase respiratory volume by as much as 10 times what is required for sedentary activity (Johnson, et al., 1975). Therefore, COHb levels can easily reach or exceed the 3% threshold during the strenuous activity of skating when elevated CO concentrations are present.

In their study of adult recreational hockey players in Quebec, Levesque, et al. (1990), recommended an average CO concentration of 20 ppm for the duration of a hockey game (90 minutes). They show that for each 10 ppm of exposure to CO in the air, the hockey players absorb enough CO to raise their COHb levels by 1%. They measured alveolar CO levels in players 15 minutes before and 15 minutes after a hockey game. If 3% COHb is the threshold for symptoms to occur and nonsmokers have an existing COHb level of 1%, raising the COHb level by more than 2% (> 20 ppm exposure for about 90 minutes) exceeds the 3% threshold for symptoms. The researchers contend that allowing this to occur is similar to making a hockey player adapt to a toxic gas so s/he can play.

The current ACGIH-TLV (3 ppm) for NO_2 has been established to minimize the potential for eye, mucous membrane and respiratory tract irritation in workers. The short term exposure limit (STEL), normally a 15-minute TWA, of 5 ppm has been established to reduce sensory irritation effects, as well as possible pulmonary edema that could be induced from repeated exposures to workers at excursions above the TLV-TWA (ACGIH, 2001).

State Regulations & Possible Control Measures

The best method of control is to eliminate the source of CO or NO_2. That is, eliminate fossil-fuel-burning combustion engines and replace them with electric motors. Electric resurfacing and edging machines have significantly lowered CO and NO_2 emissions (Brauer, Lee, Spengler, et al., 1997). If this cannot be done, engineering controls (use of local exhaust ventilation when the engine is warming up inside a building) offer the next best control measure. Dilution ventilation can reduce airborne concentrations of CO, but cannot be used alone, as it does not remove the hazard.

States and sports-governing bodies have identified the hazards of CO and NO_2 in ice arenas and have made recommendations/regulations to lower exposures by increasing ventilation, air monitoring and other measures. Only three states (Massachusetts, Minnesota and Rhode Island) currently have legal requirements for air quality in indoor ice arenas. Massachusetts' legal requirements for indoor air quality in ice arenas is the most stringent (Massachusetts Department of Public Health, 1997).

The Commonwealth of Massachusetts stipulates that both CO and NO_2 air samples must be taken at least twice during the week and at least once on weekends. Air concentrations inside the ice arena must be maintained below 30 ppm for CO and below 0.5 ppm for NO_2. If levels exceed these limits, corrective actions (such as increased ventilation) must be taken and documented. Additionally, ice arenas must notify the local fire department within 1 hour and the local board of health and the State Department of Health within 24 hours if concentrations of CO or NO_2 exceed notification levels (a single sample > 60 ppm CO or six consecutive samples > 30 ppm for CO; and a single sample > 1 ppm or six consecutive samples > 0.5 ppm for NO_2). If a single sample of CO exceeds 125 ppm or 2 ppm NO_2, the arena must be evacuated.

The Minnesota Department of Health (Regulation 4620.3900-4620.4900) has a similar law requiring CO and NO_2 concentrations be maintained below 30 ppm and 0.5 ppm, respectively, but measurements only need be taken at least once every 7 days. Corrective action must be taken if concentrations exceed these limits, but reporting requirements to the state are much less stringent. Evacuation of the ice arena is required at the same CO and NO_2 concentrations as in Massachusetts.

Rhode Island only requires daily monitoring of CO, with an acceptable level of CO set at 35 ppm for a 1-hour average. Other requirements are included, but are less stringent than Minnesota or Massachusetts.

According to the USA Hockey website:

> USA Hockey, founded in 1936-37, is the national governing body for the sport of ice hockey in the U.S. Its mission is to promote the growth of hockey in America and provide the best possible experience for all participants by encouraging, developing, advancing and administering the sport.

Through its STAR (Serving the American Rinks) program (in association with U.S. Figure Skating), it recommends that all ice arenas follow the Massachusetts guidelines. The STAR program began in 2000 and provides education and resources for rink owners and operators throughout the U.S. (Theiler, 2011).

Pennsylvania Department of Health has issued guidelines (no laws in place) for indoor air quality in indoor rinks with a 1-hour maximum level of 20 ppm CO and 0.25 ppm NO_2, for a single air sample. Connecticut Department of Public Health also has guidelines, with limits for CO set at < 25 ppm and < 0.5 ppm NO_2, again, for any single air sample collected (STAR, 2012).

Although not required by existing law or state guidelines, CO fixed-location continuous monitors with audible and visual alarms may be installed inside rinks to act as a supplemental control measure. Fixed monitors may not be installed inside the ice rink, where exposures are most likely to cause symptoms during vigorous exercise, but they may be installed inside the arena where spectators are located. If CO fixed monitors are used, ice rink management must have a written plan in place for actions required when the monitors are activated.

EPA's Indoor Air Quality and Ice Arenas website (**www.eap.gov/iaq/ice/arenas.html**) discusses CO and NO_2 potential exposures and how to control them. The concentrations of CO listed in the Massachusetts, Rhode Island and Minnesota regulations are generally in line with the EPA NAAQS 1-hour average of 35 ppm, the Canadian NAAQO 1-hour average of 30 ppm, and the WHO 1-hour average of 26 ppm.

Levesque, et al. (1990), recommend a CO concentration of 20 ppm for a 90-minute hockey game. However, adults were evaluated for COHb levels in their study, not children. CO and NO_2 emissions should be kept as low as reasonably achievable by a combination of engineering control measures, supply air ventilation and air monitoring. House and travel league hockey directors should talk with rink owners/operators about CO and NO_2 exposures and ask to see their control

USA Hockey, through its STAR program, recommends that all ice arenas follow Massachusetts' guidelines for CO and NO_2 concentrations.

For ice arenas using propane-, diesel- or gasoline-powered resurfacing equipment, regular maintence, including tuning and emission testing, should be performed.

plan. If they do not have one, encourage them to develop one by contacting a resource such as USA Hockey. Players and parents should inquire about the CO and NO_2 control measures in place for the rinks where they or their children play.

Anecdotal evidence suggests that CO levels are lower in ice arenas in states that have regulations for indoor air quality than in states that do not (assuming that most rink owners and operators comply with the laws).

In addition to monitoring CO and NO_2 concentrations in ice arenas, the regulations in Massachusetts, Minnesota and Rhode Island stipulate that ventilation rates should be increased to lower concentrations of emissions produced by ice resurfacing equipment. ASHRAE Standard 62.1-2010, Ventilation for Acceptable Indoor Air Quality, recommends an Area Outdoor Rate of 0.3 cubic feet of outdoor air per minute (cfm)/sq ft of area for sports arenas with a notation that additional dilution ventilation and/or source controls shall be provided when combustion equipment is used. For example, in a 40,000-sq-ft arena, you would need 12,000 cfm. Of course, this ventilation air must be tempered to keep the temperature and humidity controlled inside the arena.

International Ice Hockey Federation (IIHF, 2007) recommends 25 cfm per hockey player during training and 9 cfm/spectator during a hockey game, for a small rink (seating capacity up to 2,000). For example, 9 cfm x 2,000 spectators = 18,000 cfm of tempered ventilation air. IIHF also recommends installing two ventilation units, one for the public areas and one for the rink area (2007).

Specific Control Measures

Yang, et al. (1996), indicate that the fuel type used by the ice resurfacer, the air exchange rate inside the ice arena, the air distribution inside the arena and the operation of the ventilation system all contribute to indoor air quality in ice arenas. They studied ice arenas located in the Greater Boston area and in Halifax, Nova Scotia, Canada. Ice arenas using electric resurfacing machines did not have elevated CO or NO_2 levels. Their study showed that an air exchange rate of two to three air changes per hour, with good air distribution throughout the arena, and the amount of time the ventilation system is operating, have significant impact on maintaining lower levels of indoor CO and NO_2.

The most effective measure to maintain low CO and NO_2 levels is to use electric ice resurfacing equipment and follow ANSI/ASHRAE 62.1-2010, Ventilation for Acceptable Indoor Air Quality. Many indoor rinks still use fossil-fuel-powered machines because the cost of an electric resurfacing machine is about double.

Ice arenas using propane-, diesel- or gasoline-powered resurfacing equipment can take the following steps (based on state regulations and current research) to maintain levels of CO and NO_2 that do not pose significant risk of illness.

•Maintain CO levels ≤ 20 ppm and NO_2 levels ≤ 0.1 ppm (measurements should be taken at board height, inside the boards, at the red line, 20 minutes after completion of ice resurfacing). The recommended maximum resurfacing machine use time to do this is 20 minutes after the second to last resurfacing on the busiest day of the week. The simplest instruments to use are colorometric detector tubes and their corresponding pumps (e.g., Draeger, MSA, Gastec). Remember that these tubes have a ± 25% accuracy. Therefore, if one reads a 30 ppm CO level on a detector tube, the actual CO concentration may be as high as 38 ppm.

•Catalytic converters (three-way) should be installed on all combustion engines used indoors, especially resurfacing equipment.

•Perform regular maintenance on resurfacing equipment including engine tuning and emission testing.

•Follow ASHRAE minimum guidelines for 0.3 cfm outdoor air per square ft of arena. Incorporate IIHF guidelines for installing two ventilation units, one for public areas and one for the rink. Conduct regular periodic maintenance on all ventilation systems.

•If the cited controls are not feasible, open all doors to the rink, (remember to install barricades to keep the general public off the ice during resurfacing) doors to outdoors (if feasible), and doors to the lobby (public area) to allow for as much ventilation air to enter the rink area during resurfacing and for 20 minutes after. Turn on exhaust fans. Also, reduce the number of times the ice is resurfaced and reduce the number of times edging is performed.

•Warm up the ice resurfacing equipment outdoors or install local exhaust ventilation where resurfacing equipment is warmed up and vent to outdoors.

•Maintain documentation (logs) of all of these activities.

•If CO levels exceed 125 ppm or NO_2 levels exceed 2 ppm, evacuate the building.

•Rink owners/operators should train staff in CO and NO_2 hazards and how to reduce potential exposures.

•Rink owners/operators should have a written CO/NO_2 monitoring plan in place with directives on what to do for differing levels of CO and NO_2.

•Maintain air monitoring equipment per manufacturer recommendations.

•USA Hockey and STAR are always available to assist rink owners/operators.

Conclusion

CO exposures in ice arenas are directly related to the use of fossil-fuel powered equipment within an enclosed structure intended for use by the general public and the rink employees. Similar CO exposures may occur whenever gasoline- or diesel-powered equipment is used indoors (portable generators, concrete cutting saws, compressors, power trowels, floor buffers, space heaters, welding equipment, pumps and forklifts).

Lessons learned from the experiences of ice rink owners and operators may assist other employers and building managers to control potential CO and NO_2 exposures.

The public health hazard of exposing children and adult skaters to CO and NO_2 poisoning can be eliminated by following the cited guidelines. Simply knowing about the potential hazards of CO and NO_2 exposure is not enough. It is up to rink owners and operators to ensure that they are not contributing to this public health hazard. **PS**

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