REVIEW

Exposure to carbon monoxide and nitrogen dioxide in enclosed ice arenas

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Occup Environ Med 2002;**59**:224–233

This article summarises the latest information on the adverse cardiorespiratory effects of exposure to carbon monoxide (CO) and nitrogen dioxide (NO_2) in enclosed ice rinks. Sources of CO and NO_2 emissions are identified, current standards for these agents, as well as methods of controlling the emissions, dispersion, and evacuation of these toxic gases are presented. A detailed literature search involving 72 references in English and French from research conducted in North America and Europe was used. Material was from peer reviewed journals and other appropriate sources. Air pollutants such as carbon monoxide (CO), and nitrogen dioxide (NO_2) which are present in enclosed skating facilities, may exacerbate a pre-existing pathogenic condition in those people who spend considerable time in these environments. Considering the popularity of ice hockey, short track speed skating, and figure skating, and the hundreds of hours that a sensitive person may spend each year in these environments, it would seem appropriate to seek more definitive answers to this important health problem. From the findings and conclusions of the research reviewed in this paper, 10 recommendations are listed.

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Accepted 17 October 2001

Over the past 30 years, there have been several documented cases of acute carbon monoxide (CO) and nitrogen dioxide (NO_2) poisoning in Canada and the United States[1–12] resulting from the release of pollutants into enclosed ice skating arenas during routine ice resurfacing. Studies from North America and Europe have documented ambient conditions that exist inside ice skating arenas.[13–33] High concentrations of pollutants have also been found in the blood of hockey players and workers in these facilities in controlled experimentation.[18 27 28 33] In Europe, NO_2 poisoning has also been shown to occur from emissions of internal combustion ice resurfacing equipment.[9] An international study[15] involving 332 rinks located in nine countries found 40% of the sampled rinks with excess concentrations of NO_2.

In North America, the States of Massachusetts,[34] Minnesota,[35] and Rhode Island[36] have enacted guidelines and air quality standards for arenas. Elsewhere, despite heightened awareness, the problem remains.[37]

As many health professionals are called upon to attend people with cardiorespiratory problems, and as there has been an alarming increase in the number and severity of problems among people exercising in these enclosed environments, as evident by the number of recent poisoning incidents,[1–12] the following information may be of some importance. The goal of this paper is to present the current state of knowledge about exposure to CO and NO_2 in enclosed ice skating rinks, and the adverse health effects of that exposure.

REVIEW OF LITERATURE

A summary of various epidemiological, environmental, and clinical investigations involving the adverse health effects of poor air quality in enclosed ice rinks on patrons and employees is presented in table 1.

The investigations presented in table 1 have several common findings. Firstly, most studies involved environmental testing after a poisoning incident. Secondly, the environmental investigations identified the emission of CO and NO_2 in the exhaust of the ice resurfacer as the major contributor of ambient pollution in the enclosed ice arena. Thirdly, high concentrations of CO and NO_2 remained in the rink due to poor natural ventilation and inadequate or malfunctioning mechanical ventilation.

Reduction strategies that were highlighted included:

(1) Regular maintenance of ice resurfacing machines.
(2) Installation of pollution control devices—for example, install catalytic convertor.
(3) Adequate ventilation.
(4) Replace fossil fueled ice resurfacing machine with electric machines.
(5) Introduction of standards and regular monitoring of the ambient conditions of the enclosed ice rink.

Many of the authors of the studies in table 1 expressed concern that exposure to high concentrations of CO and NO_2, particularly among children during exercise, can lead to acute and chronic illness. This topic will be be discussed in more detail later. Also, the limits of concentration of CO and NO_2 proposed for work environments and in arenas, control of the emissions of toxic gas, dispersion and evacuation of toxic gases,

Abbreviations: Hb, haemoglobin; COHb, carboxyhaemoglobin; CHD, cardiovascular heart disease

Table 1 Investigations of exposure to CO and NO_2 in enclosed ice rinks

Study (ref No)	Type of study	Identified risk factors	Key health effects or attack rate	Biomonitoring CO, NO_2, and key findings	Author recommendations	Follow up
1	EnI or EpI	MIR, IV	COP	Range: 25–50 ppm CO	↓ Standards for indoor air quality	?
2	EnI or EpI	gIR and pIR	COP	After incident 100 ppm CO	Adjust air fuel mixture, Warm up gIR and pIR, Shorten resurfacings, ↓ No of resurfacings	?
3	EnI or medical reports	MIR, IV	ARI	After incident 3 ppm NO_2 Temperature inversion maintained high ↑ Exposure time, ↑ Probability of poisoning	Long exhaust pipe, RMIR, ICM, AV	?
4	EnI/EpI	MIR, IV	ARI 69%, Haem 20%	After incident 3–4 ppm NO_2	Routine monitoring	?
5	EnI or clinical investigation	MIR, IV	COP Rink employees	After incident 100 ppm CO	RMIR, AV, ReIR, After warning signs, Routine monitoring, ↓ Standards for indoor air quality	After AV 23 ppm CO After ReIR 1 ppm CO
6	EnI or EpI	MIR	COP	After incident 100 ppm CO	AV, RMIR QT	After ICM, RMIR 5–10 ppm CO
7	EnI or clinical investigation	MIR, IV	ARI	After incident 4 ppm NO_2	?	?
8	EnI or EpI	MIR, IV	COP, Team A 100%, Team B 83% Medical personnel 100% Referees 50%	After incident 47 ppm CO	AV	?
9	EnI or EpI	MpIR, IV	ARI 55.6%	After incident 1250 ppb NO_2 ↑ Risk of pulmonary symptoms with ↑ time on ice	AV, ReIR, Routine monitoring Set guidelines for air quality	?
10	EnI or EpI	MIR, IV	NO_2 induced severe symptoms 82%, Mild symptoms 100%	After incident range: 0.5–1 ppm NO_2	AV, ReIR, RMIR	?
11	EnI or EpI	MIR, IV	COP 54% players, Coaches, teachers	After incident 40 ppm CO	?	?
12	EnI or clinical investigation	MIR, IV	ARI 48% players Spectators	After incident 150 ppm CO After incident 1.5 ppm NO_2	AV, ReIR, RMIR Education of staff	?
13	EnI 20 rinks	MIR, IV	?	73 ppm CO 0.1 ppm NO_2 ↑ No of resurfacings ↑ CO Rinks varied in CO	RMIR, ReIR, AV	?

Table 1 continued

Study (ref No)	Type of study	Identified risk factors	Key health effects or attack rate	Biomonitoring CO, NO_2, and key findings	Author recommendations	Follow up
14	EnI	MIR, IV	?	4240 ppb NO_2 1 hour maximal Increased NO_2	Lower NO_2	?
15	EnI 332 rinks	MIR, IV	?	40% rinks ↑ NO_2	ReIR	?
16	EnI 70 rinks	MIR	?	Indoor NO_2 10× *v* outdoor 60% Exceeded standards 1 hour standard 40% Exceeded standards 1 week average standard 1 week average 180 ppb NO_2	Long exhaust pipe AV, ↓No of resurfacings	?
17	EnI 70 rinks	MIR	?	Outdoor rink = 16.3 ppb NO_2 Indoor rink = 169.5 ppb NO_2 Indoor NO_2 10× *v* outdoor NO_2 higher in rinks with IV	Set guidelines for air quality AV, ReIR	?
18	EnI or clinical investigation	MIR, IV	↑ COHb Rink employees	Range: 55–65 ppm CO	RMIR, QT Fresh air supply to inside rink Direct exhaust link from garage to outside	?
19	EnI seven rinks	MIR, IV	?	Range: 3–57 ppm CO Ventilation system not in operation during resurfacings	Shorten resurfacings, AV, ReIR, RMIR Routine monitoring	?
20	EnI or EpI	MIR	?	50% of rinks exceeded 25 ppm CO, Range: 25–206 ppm CO, Ventilation system not in operation during resurfacings	Routine monitoring QT, AV	?
21	EnI six rinks	gIR and pIR, IV	?	gIR range: 157–304 ppm CO pIR range: 75–175 ppm CO	ICM, AV, ReIR	After ICM gIR range: 4–110 ppm CO pIR range: 0–105 ppm CO
22	EpI	Tobacco smoke	?	1110–1700 ppm CO_2 237 ppb NO_2	?	?
23	EnI or clinical investigation	MIR	ARI	Increased NO_2	Corticosteroid treatment	Condition improved
24	EnI four rinks	MIR, IV	?	Range: 5–110 ppm CO 22.5 ppm caused various CO symptoms	AV, ReIR, ICM, RMIR, Warm up machine, Shorten resurfacings, Open doors of rink, During resurfacings, QT, Routine monitoring	?
25	EnI six rinks	MIR	?	Range: 4–117 ppm CO Range: 342–2729 ppb NO_2 Outdoor = 37 ppb NO_2	1 hour maximal Allowable 20 ppm CO and 25 ppb NO_2	?

Table 1 continued

Study (ref No)	Type of study	Identified risk factors	Key health effects or attack rate	Biomonitoring CO, NO_2, and key findings	Author recommendations	Follow up
26	EnI	MIR	?	1 week average pIR: 206 ppb NO_2 gIR: 132 ppb NO_2 eIR: 37 ppb NO_2	AV, ReIR, ICM, RMIR Routine monitoring	Engineering controls: AV ↓ NO_2 65%
27	Exposure-absoption	?	?	Linear exposure-absoption relation	↓ CO in rinks	?
28	Exposure-absoption 10 rinks	MIR	?	Range: 1.6–131.5 ppm CO ↑ 10 ppm CO = ↑ COHb 1%	CO standard of 20 ppm for 90 minutes in rinks	?
29	EnI	MIR, IV	?	Increased CO	AV, long exhaust pipe RMIR, ICM, QT Open doors of rink during resurfacings, Warm up machine, Flexible exhaust hose with direct link to outside	?
30	EnI	MIR	?	1 hour average 17–29 ppm CO 0.14–3.96 ppm NO_2	↑ CO gIR ↑ NO_2 pIR	?
31	EnI	MIR	?	23% Exceeded standards	Enforce regulations	?
32	EnI	MIR, IV	?	Range: 50–100 ppm CO	Routine monitoring	After RMIR, AV 2–3 ppm CO
33	EnI or EpI six rinks	MIR, IV	5×COHb	82% Exceeded standards Range: 23–90 ppm CO	RMIR, AV, ReIR	?

EpI, epidemiological investigation; EnI, environmental investigation; MIR, malfunctioning ice resurfacing machine; gIR, gasoline resurfacing machine; pIR, propane resurfacing machine; eIR, electric resurfacing machine; ppm, parts per million; ppb, parts per billion; IV, inadequate ventilation; RMIR, regular maintenance of ice resurfacing machine; ICM, install catalytic muffler; ReIR, replace with electric ice resurfacing machine; AV, adequate ventilation; ARI, NO_2-induced acute respiratory illness; Haem, NO_2 induced haemoptysis; COP, carbon monoxide poisoning; QT, qualified technican.

Table 2 Arenas with a concentration of CO above 25 ppm[37]

Year	Province or state	Total arenas tested (n)	Arenas with air contamination (n)
1971	Minnesota	18	13
1976	Quebec	16	13
1978	Massachusetts	8	6
1980	Ontario	4	1
1984	British Columbia	64	32
1989	Quebec	10	3
1989	Quebec	45	23

method of measuring ambient CO and NO_2, and recommendations relative to ventilation will be discussed.

CONTAMINANTS

Many noxious compounds are produced within enclosed ice arenas. These include various oxides of carbon, oxides of nitrogen, aldehydes, particulate matter in a wide range of sizes, and various highly toxic volatile organic compounds. Point sources of these agents include standard resurfacing equipment, food preparation equipment—for example, deep fryers of the rink's restaurant—refrigeration units, and smoking among patrons. However, this paper will focus on the two contaminants most often cited as the prime sources of cardiorespiratory distress, CO and NO_2.

It can be seen from table 1 that CO is the gas most often cited in academic reports and the media as responsible for intoxication in ice skating arenas. Several studies[1 2 5 6 8 10–13 18–21 23–25 30–33] have found high concentrations of CO to be common in many enclosed ice skating arenas (table 2).

Carbon monoxide is a colourless, odourless gas, which combines with haemoglobin (Hb) in the blood to form carboxyhaemoglobin (COHb). Haemoglobin has an affinity 240 times higher for CO than for oxygen.[38] There is a positive linear relation between environmental concentrations of CO and alveolar absorption of CO.[27 28] As Hb is normally responsible for the transport of oxygen, the presence of CO in inhaled air gradually results in hypoxia.[38] The mechanics of this process have been explained.

Increased CO uptake shifts the oxyhaemoglobin dissociation curve to the left and oxygen tension is reduced.[39] In response, ventilation rate will increase. The increase in ventilation results in a larger amount of inhaled CO% in the alveoli. More CO is absorbed into the blood, and CO toxicity becomes more pronounced. This cycle will continue to a point where the victim cannot function.

The brain, heart, and exercising skeletal muscles tend to be the most sensitive targets for CO.[38] Clinical reports and controlled experimentation have shown that a particular group of symptoms are associated with specific concentrations of COHb (table 3). At low concentrations of COHb, vision is altered and the arteries dilate. Nausea, headaches, and disorientation occur at higher concentrations. Very high concentrations can be life threatening.[39]

Uptake of CO during exercise has been shown to be three to four times greater than at rest.[40] The exposure-absorption studies of Lévesque *et al*[27 28] and Spengler *et al*[33] found a linear relation between percentage saturation of COHb in hockey players and exposure time and concentrations of CO. Lévesque *et al*[27 28] have shown that for each 10 parts per million (ppm) of CO in an arena, an adult male hockey player, during a 1.5 hour game of hockey, will have a COHb increase of 1.0%. Spengler *et al*[33] found that a mean environmental concentration of 22.5 ppm CO is sufficient to raise the average COHb concentration in hockey players from 1.1% to 3.2%.[24] This concentration has been exceeded by most arenas tested in various studies.[2 6 7 14 24 29 31] Several studies have suggested that high risk people (children, elderly people, people with cardiovascular inefficiencies, or pregnant women) were more susceptible to increased concentrations of COHb while participating in or observing activities in enclosed rinks.[5 13 24 27 28 31 33]

As well as the acute adverse health effects of CO poisoning, research has suggested that long term exposure to CO can increase the risk of cardiovascular heart disease (CHD).[24] For people who have CHD, exposure to increased concentrations of COHb can lead to myocardial ischaemia, abnormal cardiac rhythms or arrhythmias, or in severe cases, myocardial infarction.[41–43]

During exercise, venous oxygen tension has been shown to decrease with exposure to CO, leading to an increase in heart rate, cardiac output, and coronary artery flow.[44] People with CHD are already compromised by the limited circulatory capacity of the coronary system, further predisposing them to exercise induced angina.[45]

Along with the adverse effects placed on the cardiorespiratory system, low level exposure to CO has been associated with impaired neuropsychological function.[46] Attention span, memory, cognitive planning, and information processing have been shown to be jeopardised. In cases of CO poisoning, neuropathological hippocampal changes and diffuse cortical atrophy have been found with magnetic resonance imaging.[47]

Carbon monoxide is a byproduct of the incomplete combustion of the organic fuels used by the internal combustion engine of the ice resurfacer. Even a well tuned gasoline or propane driven internal combustion engine will produce a certain quantity of CO.[13 30]

These emissions can be amplified by reductions in the air/fuel relation.[13] In an environmental investigation, Johnson *et al*.[11] found 115 ppm of CO in the exhaust of a gasoline powered ice resurfacer after the addition of a catalytic convertor. The findings of the studies presented in table 1 are suggestive that an interaction between the adverse health effects on

Table 3 Symptoms associated with the absorption of COHb[37]

COHb concentration	Effects
0.0%–2.5%	No apparent symptoms
2.5%–5.0%	Altered vision Arterial dilation Reduced attention span particularly while driving an automobile
5.0%–10%	Altered brightness sensitivity Unusual increase in strained breathlessness Distortion of fine manual dexterity
20%–30%	Headaches Start of nausea Coordination problems
30%–40%	Severe headaches Dizziness Nausea and vomiting Judgement alteration
40%–50%	Aggravation of the same symptoms Confusion
50%–60%	Loss of consciousness Convulsions
>60%	Coma Respiratory arrest Death

Table 4 Limits of concentration of gas proposed in work environments and in arenas[37]

	CO (ppm)		NO_2 (ppm)
	1 h	8 h	8 h
Work environment:			
American Conference of Government Hygienists[56]	–	50	3
Building Code of Québec[37]	400	50	3
Oatman and Zetterlund[31]	200	35	5
Arenas:			
Luckhurst and French (Department of Health and Social Development, Winnipeg, Manitoba)[29]	25	12	–
MHPC, Québec[37]	30	13	–
Kwok, (Community Health Dept., Etobicoke, Ontario)[24]	25	13	–
Ontario Arenas Association[57]	35	–	–
King County Health Department, Seattle, Washington[21]	25	–	–
British Columbia Ministry of Labor[58]	25	–	–
Lévesque *et al*, DSC, CHUL, Québec[27 28]	20	–	–
Coueffin, Simon Fraser Health Unit, British Columbia[58]	25	12	–
Minnesota Department of Health[35]	–	–	0.5
National primary ambient air quality standards[59]	13	9	0.14
DSC and of Québec[37]	20	–	0.5

DSC, Departements de Santé Communautaire; CHUL, Centre Hospitalier de l'Université Laval.

employees and patrons of enclosed ice arenas and high ambient concentrations of CO from the emissions of engines of the ice resurfacer does exist.

Illness associated with CO poisoning is probably greatly underreported.[32 36] This may be due to the fact that the symptoms of CO poisoning are non-specific and may incorrectly be attributed to other causes.

The internal combustion engine of a resurfacer can also produce another gas, NO_2. Although cases of NO_2 intoxication seem less frequent or have been rarely documented it is important to recognise the symptoms. Low concentrations of NO_2 may irritate the mucous membrane of the respiratory passageways, ranging from irritation of the respiratory tract, up to acute pulmonary oedema.[4 7] The biochemical mechanism suggested for such insults to the respiratory tract is that NO_2 combines with water in the lungs producing nitrous and nitric acid.

One of the most cited incidents of NO_2 poisoning occurred in Minnesota, when 116 people attending two hockey games reported various symptoms ranging from cough (97%) to haemoptysis (35%). Hedbery *et al*[4] found 89% of the young hockey players with asthma reported more severe symptoms after exposure. In other cases, Morgan[7] and Karlson-Stilber *et al*[23] have documented pulmonary oedema in young hockey players after exposure to low concentrations of NO_2 during a hockey game. In these incidents, a malfunctioning ice resurfacer was the source of NO_2, and high concentrations remained in these rinks due to inadequate ventilation systems.

Although the factors responsible for asthma may vary among children, recent research has suggested that high concentrations of NO_2 in the enclosed ice skating arena may be associated with significantly higher percentages of asthma among young participants.[48–50] On the other hand, research has suggested that particular modes of exercise and sporting activities alone have the potential to bring about adverse effects in some children with asthma.[51 52]

It has been suggested that low intensity, long duration activities are more likely to elicit airway obstruction than high intensity, short duration activities.[51] A bronchoconstriction/bronchospasm event has been identified to be more likely in such outdoor sporting activities as cross country skiing.[52] This sport is usually performed in cold, dry air. Although some of the risk factors inherent in our indoor sport environments have been identified, the specific effects on the athletes and others in the environment needs much more study. The dearth of scientific studies seems surprising in the light of the widespread use of indoor fitness and recreation facilities for organised youth sports.

In respiratory research, attempts have been made to identify high risk environments for people with asthma. One line of research has focused on the indoor living environment of asthmatic people.[53 54] However, another indoor environment with the potential for triggering asthmatic symptoms, and therefore placing the person with asthma at high risk, is the indoor skating rink. Pelham *et al*[55] found a significant decrease in lung function values in children with asthma after activity in an enclosed ice rink versus activity in a well ventilated gymnasium and a swimming pool.

As already mentioned, children, in particular those with asthma, are at a higher risk of poisoning from ambient pollutants than adults while partaking in activities in enclosed rinks. This is evident with NO_2, which is heavier than most constituents of air, and would migrate towards the ice. In the confined space of the ice surface, with the lack of circulation due to inadequate ventilation, a temperature inversion condition would exist, trapping NO_2. The NO_2 concentrations would build in the lower breathing zone of the child, but much less so in that of an adult.

The concentration of the pollutant in ambient air has the potential to be an important feature in determining level of risk. As already mentioned, the most likely source of air pollutants in the enclosed ice skating rink is the internal combustion engine of the resurfacer. Several studies[3 4 7 9 12 16 17] hypothesised bronchoprovocation by high concentrations of irritants, particularly, NO_2.

STANDARDS

Standards have been applied for air quality in work environments. In these environments, the CO concentration may fluctuate, but the time weighted average (TWA) for an 8 hour exposure should not exceed 25 ppm.[56]

Several studies presented in table 1 recommend the establishment and enforcement of standards specific for enclosed ice skating rinks.[21 24 27–29] It has been recommended that the average concentrations of CO and NO_2 in arenas be lower than those required in the work environment. Table 4 shows some of the proposed limits for CO and NO_2, as summarised in the guidelines and recommendations for environmental safety in sporting facilities published by the Régie de la sécurité dans les sports du Québec.[37] It is important for health professionals, who may ultimately be responsible for

Table 5 Control of CO and NO_2 emissions from the resurfacer[37]

Means	Comments
Regular testing of CO	The rate of CO must be less than 0.5% for resurfacers driven by propane and exhaust pipes less than 1.0% for those driven by gasoline Testing includes samples*; Idling test after 3 minutes High rate test after 5 minutes The probable cause of an excessive quantity of CO; At idle, is a choke problem At a high rate, is an undersupply of air
Permanent installation of an apparatus to measure the concentration of gas*	Capable of immediately detecting of all abnormal concentrations of toxic gas at the opening of the exhaust pipe The installation of a warning light or of a buzzer on the instrument panel that will warn the employee of a malfunction
Regular maintenance of the motor*	General inspection and tune up of the motor every 6 motor weeks or for every 50 hours of use Inspection of contaminant emission Carburettor adjustment Carburettor cleaning Inspection of the air filter Inspection of the throttle
Motor equipped with a catalytic purifier	The purifier can reduce the emissions of CO and non-burned hydrocarbons by up to 95%. The catalytic purifier functions adequately when it is heated up (5 to 7 minutes)
Operate with an optimal air/carbon mixture	Especially for gas resurfacers. A mixture too rich (reduction of air/carbon relation) produces an excessive quantity of NO_2
Qualified personnel to operate the resurfacer*	An experienced employee can reduce the working time of the surfacer to a minimumin
Frequency of resurfacing*	Avoid if possible the surfacing between each period Space out the use to 90 minutes instead of 60 minutes

*Guidelines that can be used for all toxic emissions from the resurfacer.

the safety of athletes in these environments, to become familiar with these values and the pathological consequences of high concentrations of these pollutants.

However, in consideration of the sustained and vigorous physical effort (three or more times basal metabolic rate), the problem for those training at ice skating sports differs greatly from that of workers in the arena. At the time of skating, the respiratory rate can be 10 times higher than at rest.[55] Therefore, upon exposure to a similar concentration of CO, the rate of COHb in the blood will increase much more rapidly in the hockey player, for example, than in the arena employee.[27 28] This is particularly true for children who have a higher metabolic rate than adults.[55]

The following facts, already mentioned, would support a recommendation that the mean concentration of CO and NO_2 in arenas should be below those regulated in a work environment.

(1) For each 10 ppm of CO in an arena, an adult hockey player, on the basis of a 1.5 hour game of hockey, absorbs enough CO to increase his COHb concentration by 1.0%.[28]

(2) A threshold of 3% of COHb in the blood is sufficient to make the early symptoms of poisoning evident.[38]

(3) In general, non-smokers have a COHb of slightly less than 1%.[38]

Again health professionals must become familiar with these values.

Although the reported cases of NO_2 poisoning have been much more rare than CO outbreaks, it should still be considered a potentially serious health hazard.[4 7 10 16 17] In February 1988, in Québec, nine people showed clinical symptoms suggestive of NO_2 poisoning. Air samples indicated the presence of 3 ppm of NO_2.[3]

Again, the permissible maximum concentrations for a work environment are not appropriate for a sports environment. In the case of NO_2 as in the case for CO, the recommended reference limits for arenas are at least 10 times lower than in the occupational setting. In the State of Minnesota, air quality standards for enclosed ice arenas state that NO_2 should not exceed 0.5 ppm for a 1 hour exposure.[35] However, this criterion for a maximum limit of NO_2 in the surrounding air of an arena may be too high.

Controlled exposure studies tend to support an association between low concentrations of NO_2 and an increased probability of respiratory distress among asthmatic people. Brauer *et al* have studied bronchospasm response in asthmatic people after inhalation of 0.3 ppm NO_2 and exercising in a cold environment.[60] It has been shown that 0.2 ppm of NO_2 produces respiratory symptoms in asthmatic people performing an exercise challenge test in a cold environment.[61] Indeed, several studies have reported increased reactivity after exposure to 0.10 ppm NO_2 in asthmatic people.[62–64]

Finally, the Province of Québec has developed recommendations for monitoring air quality in arenas, with special reference to concentrations of NO_2 emitted by the resurfacing machine.[37] Although exposure to CO and NO_2 in enclosed ice arenas is a serious health hazard,[65–70] no federal policies currently exist for any contaminants in ice arenas.

Researchers from Sweden[9 14] and Finland[30] have expressed similar health concerns about NO_2 exhaust from the resurfacing machine, and have advocated close monitoring of ambient NO_2 concentrations. However, North American health professionals have recently advocated the use of electric resurfacing machines as the means of eliminating the pollution problem in enclosed ice rinks.[9 25 26]

CONTROL OF THE EMISSIONS OF TOXIC GAS

In most cases of poisoning, the source of contamination has been shown to be the ice resurfacer. As mentioned earlier, these machines are driven by an internal combustion motor fuelled by propane, gasoline, or diesel.

The combustion of motor fuel necessarily results in the formation of contaminants. However, the concentration of contaminants is determined by the efficiency of combustion of the motor fuel.[13 21] Well kept resurfacers fuelled by propane usually generate less CO than those fuelled by gasoline. As for NO_2, the differences are minimal.[13 21] Finally, resurfacers that use diesel have numerous secondary pollutants (poor odour).

A simple solution would be the purchase of an electric resurfacer. A North American company has introduced a series of these machines for commercial use. However, the cost of one such machine is 60% higher than that of the internal combustion engine machines.

Nevertheless, the initial difference becomes less important if the costs of fuel and the regular upkeep of the motor are added to the costs of the internal combustion resurfacer.

Table 6 Dispersion and evacuation of toxic gases[37]

Means	Comments
Initial operation of the resurfacer (evacuation)	The heating up of the motor is necessary for optimal functioning of the catalytic purifier. This should be done outside the arena or in a ventilated room and equipped with a flexible hosepipe at least 4 m long attached to the exhaust pipe permitting the transfer of contaminants to the outside
Vertical and lengthened (dispersion)	The exhaust pipe must be installed vertically. It must be lengthened to 2.5 meters (8 feet) above ice level. The escaping gas can thus be projected outside the temperature inversion zone
Open the doors of the rink (dispersion)	The goal of creating openings is during resurfacing to lessen the effect of isolation and to try to momentarily break the temperature inversion zone. It is nevertheless necessary to prohibit access to the ice during surfacing
Ventilation system (dispersion)	A system should be in constant operation. It must be strong enough to create air movement at ice level to achieve an exchange between the air at ice level and the surrounding air in the arena
Evacuation system of polluted air (evacuation)	The system should be in constant use when the resurfacer is used often (evening, end of the week, tournament, etc). At other times, the system must operate for at least 20 minutes after the resurfacer is shut off

Moreover, the cost of the operation and maintenance of a ventilation system to maintain an acceptable concentration of contaminants is high without taking into account the initial instillation costs.[12]

Among the resurfacers with internal combustion motors, those driven by propane emit the least pollutants.[24] It is recommended that a gasoline resurfacer should be converted to propane by changing the system of vaporisation and other necessary adjustments. These modification costs are minimal.

Nevertheless, no matter the type of fuel used, regular upkeep of the motor is essential to control the emissions of CO and NO_2. Regular verification of emissions of contaminants at the level of the exhaust pipe should be conducted. General guidelines for the control of CO and NO_2 emissions from the resurfacer are shown in table 5.

Other sources of pollutants may be the heating system—notably systems driven by gasoline.[12] These systems must be kept in optimum condition by rigorously following maintenance guides furnished by manufacturers. A general verification and a tune up of these systems every 6 weeks have been recommended.[12]

Finally, it is difficult to evaluate the contribution of cigarette smoke to the quality of the air in arenas without taking into account different dimensional volumes of the arenas. However, the presence of many smokers, particularly during tournaments, can certainly contribute to increasing the concentrations of pollutants.

DISPERSION AND EVACUATION OF TOXIC GASES

The combination of CO and NO_2 does occur in ice rinks. One question is how to minimise the exposure to such pollutants.

Arenas generally have similar configuration even though their capacities vary greatly. The ice surface is surrounded by a board barrier. In arenas equipped with spectator stands, plexiglas is mounted on the board barrier.

The barrier and plexiglas tend to limit air circulation. At ice level, the temperature is usually near 0°C. At plexiglas level, the temperature varies very little, but it can reach 5°C at the top of the plexiglas, and reach more than 15°C at stand level.[12]

This disparity in such a limited area tends to create a temperature inversion zone, trapping pollutants at ice level. Thus, after several resurfacings, the concentrations of CO and NO_2 increase to concentrations that could present a risk to the health of the people exposed,[13 21] particularly for short people, such as young children, working at high metabolic rates.

The evacuation of polluted air and delivery of a supply of fresh air is essential in the maintenance of air quality in arenas. An effective ventilation system is needed for this purpose. Guidelines for the dispersion of pollutants are presented in table 6.

The volume of the arena is the most important factor when designing the ventilation system for the removal of pollutants. Air must be exchanged at least once an hour when the arena is in operation.[58] An example of guidelines for measuring CO and NO_2 has been proposed (table 7).

To assure that pollutant concentrations are below maximum limits, the systems must: (*a*) be continually working; (*b*) distribute air adequately to ventilate the entire arena; (*c*) be in a position to disperse and evacuate toxic gases.

To determine the efficiency of a ventilation system, based on the volume of the building and two samples of CO or NO_2 taken after operation of the resurfacer at 30 minute intervals, it suffices to use the following formula first proposed by Davis and Drenchen[19]:

$$Q = \frac{2.3}{t} V \, \mathrm{Log}_{10} \frac{C}{Co}$$

Where: Q=rate of effective ventilation ($feet^3$/minute); v=volume of the arena ($feet^3$); t=interval between the samples (minutes); C=final concentration of CO (ppm); and Co=initial concentration of CO (ppm).

Table 7 Method of measuring ambient CO and NO_2[37]

Characteristic	Comment
Observed gases	Carbon monoxide (CO) Nitrogen dioxide (NO_2)
Proposed apparatus*	Manual pump for detection of material required to measure colour within the CO sensitivity range 0–50 ppm Colour measure tubes for NO_2 sensitivity range between 0 and 5 ppm
Duration of sampling	According to the directions of the manufacturer
Time of sampling†	A minimum of once weekly, at a fixed time (hour, day) corresponding to the times of greatest use of the resurfacer

*This material as well as the apparatus proposed can be bought in any store selling safety equipment. It is important that the pump and the tubes are of the same material, because they are not interchangeable. The tubes must be stored at a temperature of 0–5°C (in the refrigerator).
†At the time of special activities where there is intensive use of the resurfacer (tournament, reduction in the thickness of the ice, etc). The sampling must be done immediately after the end of the time of resurfacing. To assure a better result, it is recommended that the results be recorded in an ambient air observation register.

Table 8 Recommendations relative to ventilation[37]

Sources	Recommendation
Kwok[24]	1500 feet^3/min during the operation of the resurfacer 5000–7500 feet^3/min all of the time
Oatman and Zetterlund[31]	1700–2500 feet^3/min for arenas of 300000 12000–17500 feet^3/min for arenas of 2000000
Davis and Drenchen[19]	50000 feet^3/min during the operation of the resurfacer
Anderson[13]	10000 feet^3/min when using a propane resurfacer 15000 feet^3/min when using a gas resurfacer
American Society of Heating Refrigerating and Air-conditioning Engineers[71]	0–15 feet^3/min per person
Ontario Recreation Facilities Association[57]	300 feet^3/min for each volume^3 of the resurfacer used

Sampling procedures are presented in table 8.

To have an effective arena ventilation system, regular corrective measures (maintenance, cleaning, system modification, etc) must be taken.

CONCLUSIONS AND RECOMMENDATIONS

In this paper we have focused on two primary agents for eliciting cardiorespiratory distress in ice arenas. However, these pollutants are never isolated and little research has been done on the adverse health effects of various combinations of such noxious agents. The additive and synergistic effects of various mixtures may represent a more serious health hazard than exposure to each pollutant, separately. Research is needed to establish realistic standards for the potential high risk factors of combined concentrations of toxins in sporting and work environments. Research is essential in developing acceptable national standards of CO and NO_2 threshold limits. Criteria for the establishment of acceptable values must take into account the possible interactive nature of these agents with other pollutants. Also, the singular effects of pollutants such as particulates, refrigerants, sulfur dioxide, and volatile organic compounds have not been adequately investigated. There has been only one study which investigated particulates[30] and one involving volatile organic compounds.[23] These chemicals are very serious toxins. Even in isolation these irritants have the potential to be a serious health hazard, but in combination they may pose an even greater potential for adverse health effects. Given the concern among health professionals of the incidence of many cardiovascular and respiratory diseases, the possible role of environmental pollutants as potentiators of cardiorespiratory disease[72] merits further investigation.

Although ideally comprehensive and continuous monitoring of several known major toxic contaminants (CO, NO_2, aldehydes (acetaldehydes), small particulate matter (aerosol size of 2.5 μm) and various volatile organic compounds, benzene, toluene, *o*-xylene, *m*-xylene, and *p*-xylene) would be preferred. However, a more practicable approach is needed for the financially restrained, community based ice rink.

The following recommendations are based on the findings and conclusions of the studies in table 1 and the information presented in tables 2–8. These strategies primarily involve either reducing emissions from the ice resurfacing machine, or the evacuation of the emissions from the enclosed ice arena.

(1) Regular and proper installation, adjustments, and operation of ice resurfacing machines by a qualified technician. This would include installation of pollution control devices—for example, install catalytic convertor and a longer exhaust pipe—and mandatory safety inspections.

(2) Installation and continuous operation of an effective mechanical ventilation system. This would include a direct system from the ice surface to the outdoor environment, a direct line from the garage (with a set up for a direct line for the exhaust pipe of the resurfacer) to the outdoor environment, and a fresh air supply to the rink surface.

(3) Open rink doors during and after resurfacings.

(4) Replace the fossil fuelled ice resurfacing machine with an electric machine.

(5) Introduction of standards and regular monitoring of the ambient conditions of the enclosed ice rink (active enforcement of these standards required).

(6) Establish air quality standards: 1 hour maximal allowable of 20 ppm CO[17 28] and 200 ppb NO_2.[24]

(7) Develop an inexpensive, but effective toxic chemical surveillance programme.

(8) Train and test (certify) operators in effective techniques of reducing the frequency and shortening the duration of resurfacing, and to operate the resurfacer in a manner to minimise emissions (proper warm up and less acceleration during the resurfacing process).

(9) Installation of visual warning signs of the potential symptoms and hazards of CO and NO_2 poisoning, as well as education seminars for rink staff, coaches, parents, and patrons of ice rinks of all ages.

(10) Develop a prudent emergency plan in the case of a poisoning incident.

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