BEST PRACTICES FOR IMPROVING AIR QUALITY IN ICE ARENAS

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1.0 EXECUTIVE SUMMARY

In Canada, over 2,000 indoor ice arenas are used routinely by hundreds of thousands of people for activities such as hockey, figure skating, ringette, and recreational skating (IIHF 2020). Resurfacers and edgers used to maintain the ice surface in these arenas are typically powered by internal combustion engines, which emit air pollutants such as carbon monoxide (CO) and nitrogen dioxide (NO_2), both of which are associated with adverse health effects. Recommendations for reducing the levels of air pollution in arenas can provide a framework for minimizing the risk of health effects for people using ice arenas, including vulnerable populations (e.g., children and the elderly).

This guidance is intended to help public officials, managers, and employees maintain and improve air quality in ice arenas by providing evidence-based recommendations. It also provides an overview of the potential health effects of poor air quality in ice arenas as well as detailed guidance for the development of a monitoring and response framework.

Implementing best practices for improving air quality in an ice arena is a multistep process that should consider equipment options, use and maintenance of equipment, emission source reduction and removal actions, regular air monitoring, and actions for pollutant concentrations exceeding recommended health-based exposure limits. Ice arena operators and/or managers can best improve air quality and help protect occupants' health by considering ice resurfacing equipment fuel type and operation, following maintenance schedules, ensuring adequate ventilation, and improving air circulation and air pollutant monitoring and response actions to elevated CO and NO_2 levels.

As each ice arena is unique, certain situations may require a tailored approach to control pollutant levels. The strategies provided in this document can be modified as required. A checklist for improving indoor air quality, and monitoring of and responding to air pollution in ice arenas is provided in appendix A.

2.0 BACKGROUND

In Canada, over 2,000 indoor ice arenas are used routinely by hundreds of thousands of people who watch or participate in activities such as hockey, figure skating, ringette, and recreational skating (IIHF 2020).

To maintain the ice surface, ice resurfacers and edgers powered by internal combustion engines (i.e., propane, natural gas, gasoline, diesel) are typically used. This equipment emits air pollutants, CO and NO_2, as well as fine and ultrafine particulate matter and volatile organic compounds (VOCs), primarily due to incomplete fuel combustion. There are several factors that can contribute to elevated air pollutant levels in ice arenas, such as resurfacing equipment fuel type, equipment malfunction, inefficient pollutant removal through building ventilation systems, and lack of monitoring of, and response to, elevated pollutant levels.

Exposure to these pollutants, particularly CO and NO_2, are recognized to cause adverse health effects, including eye and respiratory irritation, asthma exacerbation, flu-like symptoms, difficulty breathing, and loss of consciousness or death in extreme cases. These adverse health effects, particularly for certain individuals including children, the elderly, and those with pre-existing medical conditions, are expected to be exacerbated during periods of strenuous exercise and may also be affected by cold temperature conditions consistent with those found in ice arenas (Leuppi et al. 1998). In addition to the more than 10 poisoning incidents reported in Canadian ice arenas between 2010 and 2020 (Drake et al. 2020; CTV News 2019, 2014; Global News 2019; CBC News 2015; ORFA 2015), hockey players and figure skaters have been shown to have a higher prevalence of asthma symptoms compared to the general population and other athletes, which may be exacerbated by strenuous exercise at lower temperatures (Leuppi et al. 1998).

Therefore, air pollution in ice arenas can be considered a public health issue. Improving air quality in ice arenas to help protect the health of their users and employees requires a multistep approach. Implementing best practices aimed at improving air quality in ice arenas is considered an effective and practical strategy to reduce associated health risks (ORFA 2015; New Brunswick Department of Health 2014; Beausoleil et al. 2014; Recreation Facility Association of Nova Scotia 2013; Manitoba Health Branch 2009), and requires the following:

- understanding that poor air quality in ice arenas can increase the risk of adverse health effects;
- knowledge of the sources of air pollution in ice arenas;
- knowledge of the building and equipment operations and how they can be adjusted to limit emissions and reduce the air levels of CO and NO_2;
- knowledge of how to monitor CO and NO_2; and
- ability to identify and respond to elevated CO and NO_2 levels.

The evidence-based recommendations and monitoring and response framework presented in this document are supported by results from peer-reviewed scientific studies, and guidance published by other jurisdictions.

3.0 SOURCES OF POLLUTANTS IN ICE ARENAS

Ice resurfacers and edgers powered by internal combustion engines are the primary source of pollutants within ice arenas. Air monitoring has shown that the operation of ice resurfacers running on propane, natural gas, gasoline or diesel is a major source of poor air quality in arenas (Health Canada 2021; Manitoba Health Branch 2009; Brauer et al. 1997). It should be noted that there are other sources of air pollutants in ice arenas, which are not discussed further in this document, but compared to ice resurfacers they are considered a very small contributor to combustion-related indoor air pollutants found in ice arenas, unless there is a situation of malfunctioning equipment (New Brunswick Department of Health 2014).

Other sources of air pollutants in ice arenas include:

- heaters above the spectator stands;
- cooking equipment located in kitchens or canteens; and
- infiltration of outdoor pollutants into the building.

Like ice resurfacers, it is essential that heaters and cooking equipment used in ice arenas are maintained appropriately to avoid an increased release of combustion-related pollutants.

4.0 POLLUTANTS OF CONCERN

Air in ice arenas contains several pollutants (e.g., CO, NO_2, particulate matter, VOCs) many of which have been shown to cause a variety of adverse health effects, including headache, malaise, nausea/vomiting, dizziness, cough, hemoptysis, throat irritation, dyspnea, and chest pain (Salonen et al. 2008; Guo, Lee and Chan 2004; Rundell 2003; Rosenlund and Bluhm 1999; Soparkar et al. 1993).

In recent years, there have been numerous reported incidents of poisonings in Canadian arenas, frequently occurring during periods of increased ice resurfacing (such as hockey tournaments), and often as a result of ice resurfacer malfunctions or inadequate ventilation (Drake et al. 2020; CTV News 2019, 2014; Global News 2019; CBC News 2015; ORFA 2015). Resurfacer malfunctions can occur due to equipment age, mechanical failure or inadequate maintenance. Insufficient levels of ventilation may be the result of mechanical failure or undersized/underused systems for removing resurfacer CO and NO_2 emissions (Drake et al. 2020; ORFA 2015).

Documented adverse health effects from air pollution in ice arenas are most often from exposure to elevated levels of CO, and the observed symptoms have included headaches, nausea/vomiting, dizziness, and fatigue (Salonen et al. 2008; Paulozzi, Satink and Spengler 1991). Nitrogen dioxide poisonings have also occurred, but may be underreported due to the lack of monitoring data and the up to 48 hour-delay in the onset of adverse health symptoms (Karlson-Stieber et al. 1996). Symptoms from exposure to elevated NO_2 levels in ice arenas include shortness of breath, cough, acute respiratory symptoms, and non-carcinogenic pulmonary edema (excess fluid in the lungs) (Rosenlund et al. 2004; Karlson-Stiber et al. 1996; Morgan 1995).

This guidance focuses on CO and NO_2, which are responsible for the vast majority of documented poisonings and for which there are health-based exposure limits and readily available monitoring equipment. In addition, levels of CO and NO_2 can be considered indicative of the levels of other combustion-related pollutants present in the indoor air of ice arenas. Thus, strategies aimed at reducing CO and NO_2 in this guidance should also be effective at reducing levels of other pollutants coming from resurfacing equipment exhaust. It is important to note that Health Canada's Residential Indoor Air Quality Guidelines (RIAQGs) discussed below were developed specifically for residential environments and not for recreational facilities. However, they do provide an understanding of the health risks posed by air pollutants observed in ice arenas as well as health-based exposure limits to support the implementation of a monitoring and response framework.

4.1 CARBON MONOXIDE

Carbon monoxide is an odourless, colourless gas that is produced by incomplete fuel combustion in ice resurfacing equipment as well as spectator heaters and cooking equipment located within the arena. Infiltration of outdoor air can also contribute to indoor levels of CO.

4.1.1 Health effects

People exposed to CO may experience flu-like symptoms such as headaches, fatigue, dizziness, weakness, nausea, vomiting as well as chest pain, shortness of breath, impaired motor function, and confusion. Inhaling very high levels of CO can cause convulsions, loss of consciousness, and death (Health Canada 2010).

Children, the elderly, and those with pre-existing heart disease as well as those engaged in strenuous physical activity are considered at an increased risk of the health effects of low-level CO exposure (Health Canada 2010).

4.1.2 Exposure

Health Canada's RIAQG for CO recommends a short-term (1-hour) exposure limit of 25 ppm and a long-term (24-hour) exposure limit of 10 ppm.

The time period indicated in brackets above is the recommended sampling time that this guideline is based on.

Documented cases of CO poisonings from resurfacer emissions in arenas have reported levels of 40–170 ppm (Creswell et al. 2015; Salonen et al. 2008; Paulozzi, Satink and Spengler 1991). However, there may be an underreporting of CO-related illnesses because some of the non-specific poisoning symptoms may be attributed to other causes (Pelham, Holt and Moss 2002). One-hour average CO levels in the 16 arenas measured by Health Canada were always below 20 ppm and generally between 0 and 10 ppm; however, two arenas had multiple 1-hour average levels above the 10 ppm long-term guideline (Health Canada 2021, 2015).

4.2 NITROGEN DIOXIDE

Nitrogen dioxide is a reddish-brown gas with a pungent acrid odour. It is heavier than air and as a result may accumulate closer to the ice surface and occupant breathing zones (Pelham, Holt and Moss 2002). It is produced within arenas as a by-product of combustion equipment exhaust and can also infiltrate from outdoor sources.

4.2.1 Health effects

Exposure to NO_2 (≥ 0.09 ppm) in the air can irritate the eyes, nose, throat, and lungs, potentially causing cough, shortness of breath, tiredness, and nausea. Studies have shown that increased respiratory inflammation and decreased lung function have been associated with exposure to levels of NO_2 measured in ice arenas (Health Canada 2021, 2015). The health effects from NO_2 exposure may be immediate or in some cases delayed for one to two days, depending on the level of exposure and differences in individual susceptibility (Morgan 1995; Soparkar et al. 1993; Hedberg et al. 1989). Furthermore, associations between NO_2 exposure and rhinitis, increased asthma prevalence, and decreased lung function have been reported in hockey players exposed to high levels of NO_2 (Salonen et al. 2008; Thunqvist et al. 2002).

Asthmatics and those with other pre-existing respiratory conditions are considered at an increased risk of health effects from NO_2 exposure (Health Canada 2015).

4.2.2 Exposure

Health Canada's RIAQG for NO_2 recommends a short-term (1-hour) exposure limit of 0.09 ppm.

The levels of NO_2 in arenas during documented poisoning cases were between 1.5 and 4.0 ppm (Morgan 1995; Smith, Anderson and Anderson 1992; Hedberg et al. 1989; Dewailly, Allaire and Nantel 1988). Health Canada observed that 7 out of the 16 arenas monitored had one or more 1hour average NO_2 measurements above Health Canada's 0.09 ppm short-term exposure limit. The levels of NO_2 in these arenas ranged from < 10 to 950 ppb (Health Canada 2021). These levels tended to be lowest in the morning and increased throughout arena operating hours. The levels of NO_2 indoors never returned to ambient (outdoor) levels for the majority of these arenas, more than half having NO_2 levels at least twice those concurrently measured outdoors.

4.3 OTHER POLLUTANTS

As previously mentioned, other air pollutants that may be found in ice arenas include fine and ultrafine particulate matter, and VOCs (McLennon and Hon 2017; Rundell 2003). These pollutants are primarily emitted from combustion engines and are expected to be reduced by following the same recommendations used to control CO and NO_2. For information on the health effects of indoor air pollutants, including those produced by combustion, visit the Government of Canada's air contaminants and health webpage.

5.0 RECOMMENDATIONS FOR IMPROVING AIR QUALITY IN ICE ARENAS

To support the improvement of air quality in Canadian ice arenas, Health Canada has developed the following series of recommendations. The implementation of these recommendations is intended to reduce people's exposure to combustion-related pollutants produced in the arenas and related risks of adverse health effects. This section provides evidence-based recommendations for controlling emissions of CO and NO_2, reducing levels of these pollutants by improving ventilation, and monitoring and responding to air quality issues.

5.1 ICE RESURFACING AND EDGING

5.1.1 Fuel type

Electric-powered equipment is the best option for eliminating CO and NO_2 emissions in ice arenas. Arenas using electric resurfacers have been shown to have CO and NO_2 levels similar to concurrent levels outside the arena, consistently below 1.0 ppm and 0.02 ppm, respectively (Health Canada 2021; Pennenan et al. 1998; Brauer et al. 1997). While the cost of purchase of electric-powered equipment is often greater than that of fuel-powered equipment, maintenance and operating costs are typically lower. In addition, arenas using electric ice resurfacers can experience cost savings from the reduced necessity for frequent ventilation and associated heating and cooling expenses (AQAIRS 2013). Using electric ice resurfacers is the most effective method for improving and maintaining low levels of air pollution in ice arenas.

Among fuel combustion-powered ice resurfacers, diesel- and gasoline-powered ones emit the highest levels of air pollutants, particularly CO and fine particulate matter, followed by propane- and natural gas-powered ones, which emit significantly less combustion-related pollutants (New Brunswick Department of Health 2014; Pennenan et al. 1998). Therefore, use of diesel- and gasoline-powered ice resurfacers should be avoided. However, it should be noted that propane- and natural gas-powered ice resurfacers emit slightly more NO_2 than diesel- or gasoline-powered ones. In a study of 332 arenas, the median NO_2 levels were 0.075 ppb and 0.1 ppb in arenas using gasoline- and propane-operated resurfacers, respectively (Brauer et al. 1997; Brauer and Spengler 1994). The limited number of available studies have not shown large differences in pollutant emissions between propane- and natural gas-powered ice resurfacers (Health Canada 2021) or, more broadly, other vehicle types (Howes and Rideout 1995).

Fuel-powered edgers, particularly those running on gasoline or diesel, can release large amounts of air pollution and should be replaced with electric ones if possible (New Brunswick Department of Health 2014; Recreation Facility Association of Nova Scotia 2013). A study of the 7-day pollutant levels in 332 arenas located in 9 countries found that arenas using fuel-powered edgers had significantly higher levels of NO_2 than those that did not (Brauer et al. 1997).

5.1.2 Pollution control

Catalytic convertors can significantly reduce the amounts of CO, NO_2, and other pollutants in ice resurfacer exhaust emissions. Two-way catalytic convertors are effective at removing CO and hydrocarbons from resurfacer exhaust, while three-way catalytic convertors also remove nitrogen pollutants, including NO_2. Existing ice resurfacers fitted with three-way catalytic convertors emit less air pollutants than ones fitted with two-way catalytic convertors (AQAIRS 2013; Manitoba Health Branch 2009; Pennanen et al. 1997). A study in British Columbia found that the emissions from a propane-powered resurfacer that switched from a 2-way to a 3-way catalytic convertor had NO_2 and CO levels reduced by 87% and 57%, respectively (McNabb, Kostiuck and Brauer 1997).

≋ RECOMMENDATIONS

- Use electric ice resurfacers and edgers, which are the best equipment choices from an air quality perspective, to eliminate the main sources of CO and NO_2 in arenas.
- Avoid gasoline- and diesel-powered resurfacers and edgers. Propane and natural gas are preferred fuel alternatives from an air quality perspective if electric options are not available.
- Fit ice resurfacers with internal combustion engines with three-way catalytic convertors, if possible.

5.2 EQUIPMENT OPERATION AND MAINTENANCE

Ice resurfacers, edgers, and catalytic convertors should be regularly maintained according to the manufacturer's schedule and recommendations (New Brunswick Department of Health 2014). Regular maintenance identifies and helps prevent equipment malfunctions, which could result in elevated emissions of CO and/or NO_2 (Manitoba Health Branch 2009) and CO and NO_2 poisoning events (Drake et al. 2020). Resurfacer engine maintenance should also include exhaust gas analysis and engine adjustments to reduce air pollutant emissions. The richness of the fuel or airfuel ratio can be adjusted to decrease pollution emissions (Recreation Facility Association of Nova Scotia 2013; Roberge 2000; Hedberg et al. 1989; Anderson 1971). Poor engine tuning was partially responsible for CO levels above 100 ppm in three Swedish arenas between 1992 and 1997, with approximately 200 people experiencing adverse health effects (Salonen et al. 2008).

Resurfacers should be warmed up outdoors prior to use, or in a well-ventilated room with a CO alarm or one where the exhaust can be directly vented outside (away from air intakes or open doors). It is important to note that catalytic convertors will not effectively remove pollutants from the equipment's exhaust until they reach their operating temperature (US EPA 2020a; Recreation Facility Association of Nova Scotia 2013; Manitoba Health Branch 2009).

The ice resurfacer exhaust pipe should extend above the plexiglass protective barrier surrounding the ice surface, if possible. Shorter exhaust pipes can result in emissions being trapped inside the barrier, settling above the ice surface and in the breathing zone of people using the ice (New Brunswick Department of Health 2014; Recreation Facility Association of Nova Scotia 2013; Manitoba Health Branch 2009).

The number of resurfacings should be limited, where possible, especially on busier days such as weekends, during tournaments or other events (Pelham, Holt and Moss 2002). Lee et al. (1994) found significant reductions in NO_2 when the number of resurfacings was limited. Whenever a greater frequency of ice resurfacing is necessary, ventilation should be increased.

Ice maintenance should be scheduled on days/times where there can be limited exposure, such as at the end of daily operations or on days where there is less public use of the facility (Manitoba Health Branch 2009). The prolonged use of an ice resurfacer and/or edger can result in high levels of air pollutants (ORFA 2009). When gasoline-powered edgers were performing ice maintenance, levels of CO and NO_2 have been shown to be greater than 100 ppm and 0.4 ppm, respectively (Cox et al. 2019).

Outdoor vehicle emissions can enter the arena and affect the air quality indoors. Preventing vehicle access or idling near arena entrances, doors or air intakes can reduce outdoor exhaust pollution entering the arena (ORFA 2015; Recreation Facility Association of Nova Scotia 2013; Manitoba Health Branch 2009).

≋ RECOMMENDATIONS

- Follow regular maintenance schedules as per manufacturer's instructions for ice resurfacers and edgers as well as heaters located in the spectator area and other fuel-burning equipment.
- Warm up resurfacers outdoors or in a room equipped with a CO alarm and a dedicated ventilation system for at least five minutes prior to use to allow catalytic converters to reach their appropriate operating temperature.
- Extend the exhaust pipe of the ice resurfacer to above the protective barrier surrounding the ice surface.
- Limit the number of resurfacings, where possible.
- Schedule maintenance when there is reduced public activity.
- Eliminate vehicle idling near entrances or air intakes.

5.3 VENTILATION SCHEDULES AND IMPROVEMENT OF AIR CIRCULATION

5.3.1 Ventilation schedules

A Health Canada pilot study (2021) demonstrated that levels of NO_2 are frequently two to five times higher in ice arenas before the start of daily resurfacing than the concurrent levels measured outside the building. Levels of NO_2 were observed to increase during the arena's operating hours and not returning to levels found outdoors by the following day. However, in general, ten minutes of ventilation (i.e. drawing in fresh air and exhausting outside) per hour during operating hours reduced the levels of CO and NO_2 in these ice arenas. In addition to ten minutes of ventilation per hour during operating hours, continuously running the ventilation system for two hours after operating hours (a "flush-out") reduced these levels particularly in arenas that had high levels of CO or NO_2 prior to the study intervention. As ventilation systems in Canadian arenas vary considerably in their capabilities to remove pollutants, adjustments to this guidance can be made when necessary. While overnight flush-outs may be useful for reducing pollutant build-up from the day's resurfacing, it is meant to be used in addition to regular hourly ventilation schedules. Relying solely on overnight flush-out without regular ventilation throughout the operating hours would likely lead to an accumulation of CO and NO_2 during operating hours.

Note that installing an automated ventilation system with a programmable timer is ideal for implementing overnight ventilation flush-outs and achieving hourly ventilation during operation (Health Canada 2021).

Health incidents related to poor air quality have occurred during tournaments and other events where there is increased resurfacing. Increased ventilation and air pollutant monitoring on those days should be planned to avoid these incidents (New Brunswick Department of Health 2014). About 100 people received medical attention after a hockey tournament in Wisconsin in 1992 where the CO levels were between 45 and 165 ppm. The subsequent investigation concluded that the high levels of CO were the result of insufficient ventilation and air monitoring, and a pollution control malfunction with the resurfacer (Creswell et al. 2015). In a similar Canadian incident, insufficient ventilation in an Ottawa arena resulted in 20 players requiring urgent medical attention to treat symptoms of CO poisoning (CTV News 2014). In 2015, over 100 people in Nunavik, Quebec, were exposed to high levels of NO_2 during a hockey tournament. Several of them exhibited symptoms of NO_2 poisoning, which required immediate medical attention. Investigators found that the increased number of ice resurfacings during the tournament, combined with insufficient ventilation and pollutant monitoring, contributed to the high pollutant levels (CBC News 2015).

On maintenance days where there is extended use of ice resurfacers (Cox et al. 2019), ventilation should be increased, if not run continuously, to prevent build-up of high levels of CO and NO_2. Maintenance work should be completed on days where adequate ventilation can remove the CO/NO_2 before public activity in arenas resumes (ORFA 2015) or at the end of the daily operating hours (Manitoba Health Branch 2009). In 2019, 12 out of 16 hockey players had symptoms of NO_2 poisoning after a practice in a Kelowna, British Columbia, arena. The subsequent investigation found that the elevated NO_2 level was the result of inadequate ventilation during and following the 3.5 hours of ice maintenance several hours before the hockey practice (Drake et al. 2020). A similar incident occurred in New Hampshire, USA, in 2011 where over 30 players and spectators developed symptoms consistent with NO_2 poisoning after a hockey game. Six hours prior to the game, 1.5 hours of ice maintenance had been completed without mechanical ventilation due to an unrecognized system malfunction (Altomare et al. 2012).

5.3.2 Improving air flow

Opening gates around the ice surface can increase air flow over the ice and reduce the amount of CO and NO_2 trapped inside the protective barrier (Manitoba Health Branch 2009). If available, ceiling circulation fans (or other devices intended to create updraft) should be run as much as possible during operating hours to help circulate the air and reduce the amount of heavier-than-air pollutants (such as NO_2) from accumulating above the ice surface (Brauer and Spengler 1994). Electrically connecting ceiling circulation fans to switches for the lights above the ice surface ensures they are in operation when the arena is in use.

RECOMMENDATIONS

- Operate ventilation system for at least 10 minutes per hour of operation, and ideally continuously during resurfacing.
- Include an overnight two-hour "flush-out" in the ventilation strategy.
- Consider installing automated ventilation systems with programmable timers to schedule daily ventilation events.
- Increase ventilation on days when there are increased resurfacings, such as tournaments and other events that generate more indoor air pollutants than usual.
- Open all gates around the ice surface during resurfacing to increase air circulation.
- If available, run ceiling fans continuously to increase air circulation and updraft, ideally with the fans connected to the arena light switches.

6.0 AIR POLLUTANT MONITORING AND RESPONSE IN ICE ARENAS

6.1 AIR POLLUTANT MONITORING

6.1.1 Where to sample

Monitoring CO and NO_2 in arenas is critical for detecting high levels and reducing possible occupant exposure. Average CO and NO_2 air samples should be collected approximately one metre above the ice surface (approximate board height). Nitrogen dioxide has been shown to accumulate at this level above the ice surface due to the fact that it is heavier than most constituents of air and migrates towards the ice surface. Insufficient air circulation inside the protective barrier, combined with a temperature inversion condition due to cold ice surface can result in the accumulation of the trapped pollutants (Pelham and Holt 2002).

In addition, one metre is the breathing zone for many children, which are considered susceptible to the health effects of air pollution. During monitoring of pollutant concentrations near the ice surface, levels in the timekeeper's box were correlated with levels on the ice surface and spectator areas (Health Canada 2021). Thus the timekeeper's box can be considered a good option for a sampling location. Being easily accessible and protected, it is also ideal for monitoring, provided it is not entirely enclosed from the ice surface and spectator areas. Arenas that have natural gas or propane heaters in the spectator areas should consider monitoring those locations as well.

All arenas should have functioning CO alarm systems. Carbon monoxide alarms with a continuous digital low-level CO display can be installed in various locations around the arena and the levels regularly monitored and documented as per manufacturer's instructions. Monitoring levels of CO below those which would trigger an alarm signal could help protect susceptible populations from low-level CO exposure and avoid emergency evacuations and CO poisoning events.

6.1.2 How long to sample

Health Canada's short-term health-based exposure limits for CO and NO_2 are based on a one-hour recommended sampling time. Therefore, it is recommended to collect one-hour average samples for a general comparison to health-based exposure limits, and thus support implementation of a monitoring and response framework (Health Canada 2015, 2010, 1987). Shorter time period spot-sampling is not appropriate for regular monitoring samples, but may be used to check the effectiveness of actions to reduce identified air quality problems or to assess if further sampling is required when a problem is suspected.

Continuous CO and NO_2 monitors are the best option for arenas to monitor pollutant levels and quickly react to pollutant concentrations at or above the action levels (Beausoleil et al. 2014; AQAIRS 2013). By replacing the need for one-hour sample collections, these systems allow arena operators to check the air quality levels daily or more frequently, which may reduce the incidences of exposure to elevated levels of CO and NO_2. The continuous monitor system can also be integrated into the ventilation system, where the detection of an action level activates the ventilation until the air quality has returned to acceptable levels (Beausoleil et al. 2014; AQAIRS 2013). It is recommended to implement continuous CO and NO_2 monitoring, if possible.

6.1.3 When to sample

The one-hour average or continuous measurements for CO and NO_2 should be collected routinely, preferably during periods of frequent resurfacing (Manitoba Health Branch 2009). As the levels of CO and NO_2 have been shown to accumulate during the day and peak in the evening (Health Canada 2021), monitoring in the evening may capture the highest daily concentrations. Arenas that have continuous monitoring systems should be checking and recording pollutant levels as often as possible, routinely, and more often during tournaments or other events where there may be increased resurfacings. Continuous monitoring systems can be programmed to trigger alarms or warnings when action levels are reached.

During special events that may cause higher than normal air pollution levels, regular monitoring schedules should be reconfigured. Special events may range from hockey tournaments (where there may be an increased frequency of ice resurfacing) to events featuring other types of combustion vehicles (e.g., monster truck shows, motocross). In these cases, arena operators should increase the frequency of sampling or, if available, use continuous sampling and monitor levels as often as possible (New Brunswick Department of Health 2014).

6.1.4 Types of monitors

Monitors need to accurately capture levels of CO and NO_2 in ice arenas. The table below provides specifications required for monitors to measure continuously or take one-hour averages of these pollutants.

TABLE 1: Minimum pollutant monitor requirements for air quality sampling in ice arenas

Pollutant	Resolution	Range	Precision
CO	1 ppm	0–200 ppm	± 5%
NO_2	0.02 ppm	0–10 ppm	± 5%

Health Canada recommends using an NO_2 monitor designated as a Federal Reference Method (FRM) or Federal Equivalent Method (FEM) (US EPA 2020b). Caution should be taken when considering the use of electrochemical, metal oxide, or other low-cost sensor technology as it may not meet the same specifications as an FRM/FEM to accurately measure NO_2 at concentrations found in ice arenas (Health Canada 2021).

Facility operators need to ensure their air monitors are operational at the temperatures and humidity levels in their arena. They should follow manufacturers' instructions regarding calibration and maintenance requirements.

≋ RECOMMENDATIONS

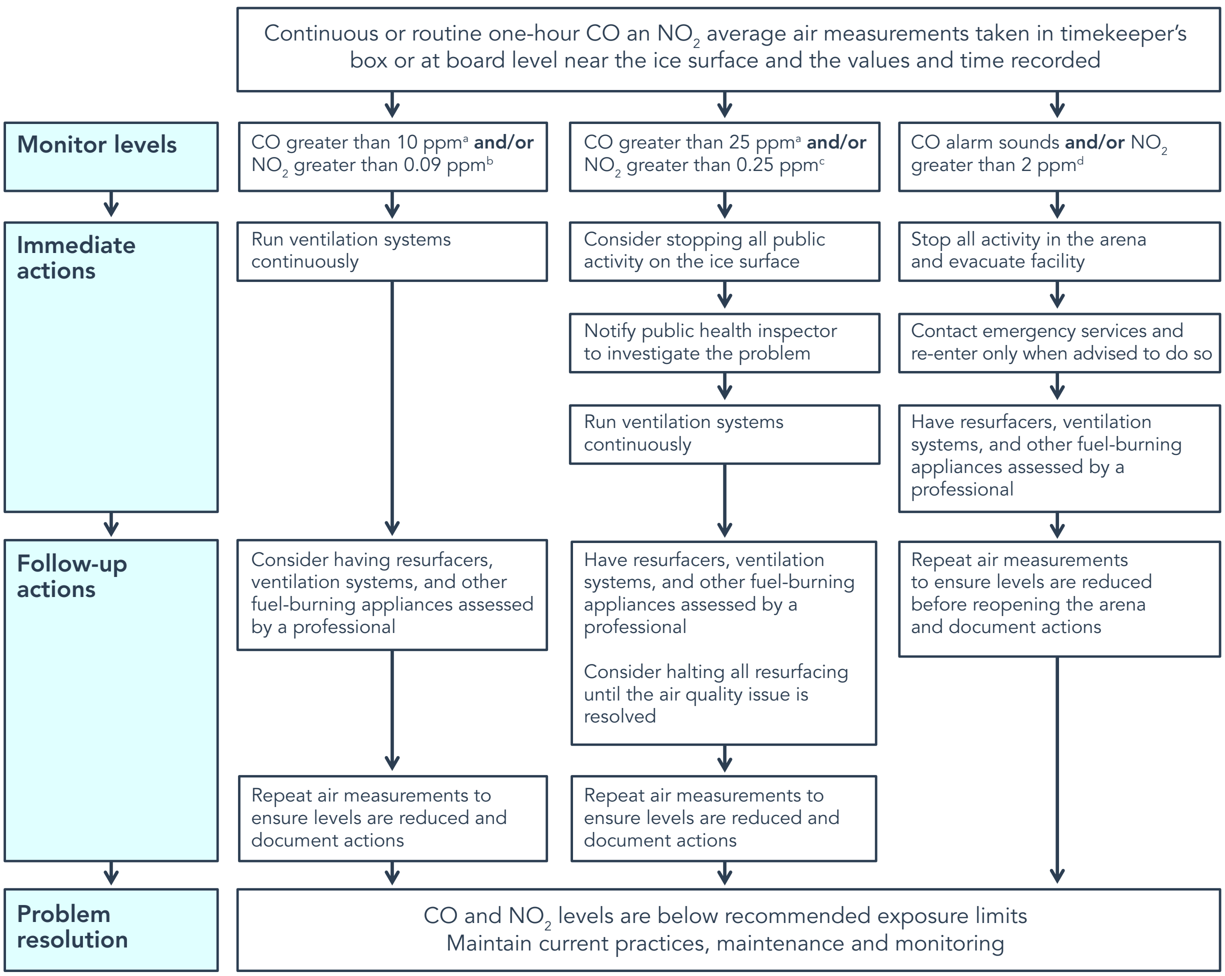
- Collect samples on or near the ice surface or in the timekeeper's box (provided it is not entirely closed off from the ice surface).
- Take samples at breathing height (approximately one metre) in the chosen monitoring location.
- Install and maintain CO alarms throughout the arena.
- Use continuous CO and NO_2 monitors, which are the best option for quickly identifying elevated pollutant levels. Check and document levels daily at a minimum.
- When possible, couple continuous air monitoring systems with mechanical ventilation to trigger the ventilation system when pollutant concentrations reach action levels.
- If continuous CO and NO_2 monitoring is not available, conduct one-hour average CO and NO_2 monitoring on a weekly basis at a minimum, on a day and time when there are the most resurfacing events. Document levels.
- Monitor on days with the most resurfacings, during the evening or near the end of daily operations.
- Ensure monitors meet the resolution, range, and precision specified in Table 1.
- Follow manufacturers' monitor maintenance and calibration schedules.
- Record and file all sampling levels, and maintenance and calibration details.

6.2 RESPONSE ACTIONS TO ELEVATED CO AND NO_2 LEVELS

Using air monitoring to respond to elevated levels or "action levels" of CO and/or NO_2 is critical in reducing potential health risks. Exposure to CO and/or NO_2 exceeding the action levels may result in health effects experienced by the public or staff inside the ice arena.

Figure 1 provides an overview of recommended actions to be taken in response to various levels of CO and NO_2. The response actions are based on Health Canada's indoor air quality guidelines (Health Canada 2015, 2010, 1987). Due to logistical challenges with measuring NO_2 concentrations at or below Health Canada's short-term RIAQG of 0.09 ppm, it may not be feasible to utilize this exposure limit in a monitoring and response framework. Therefore, the recommended response actions in this document are primarily based on a level of 0.25 ppm, which can be considered generally protective of sensitive individuals and takes into account feasibility from a monitoring standpoint (Health Canada 1987). It should be recognized that adverse health effects are possible below this threshold, particularly amongst susceptible populations.

FIGURE 1: Response actions to elevated CO and NO_2 levels in ice arenas



[a]Health Canada 2010; [b]Health Canada 2015; [c]Health Canada 1987; [d]Beausoleil et al. 2014

Consistent with best practices for monitoring and response frameworks, it is recommended that a system of air sampling documentation is implemented, including the recording of pollutant levels, sample location, and date and time of the sample. If the level of CO or NO_2 is found to be elevated, the flow chart in Figure 1 provides actions to address the issue. It is always recommended to take steps to reduce levels of pollutants inside an ice arena to as low as possible. Monitoring should continue at regular intervals until the issue is resolved. All actions should be recorded, and maintenance/calibration records for the equipment documented.

RECOMMENDATIONS

- Arenas should attempt to keep pollutant levels as low as possible using the guidance outlined in this document.
- Immediate actions should be followed when CO and NO_2 levels exceed 25 ppm and 0.25 ppm, respectively (see Figure 1 on previous page).
- Actions taken to reduce levels should be appropriately documented.

7.0 CONCLUSIONS

Canadians who regularly visit ice arenas as athletes, spectators, and general attendees to events include not only healthy adults, but also individuals susceptible to the health effects of air pollution, such as children, the elderly, and individuals with pre-existing respiratory and cardiac conditions.

At the time of this report, the majority of ice arenas used propane or other combustible fuels to power ice resurfacers. These machines emit pollutants such as CO and NO_2 inside the building, which are recognized to increase the risk of adverse health effects. Implementing best practices as well as a monitoring and response framework to improve air quality can reduce the levels of air pollutants in ice arenas and thus help protect the health of Canadians. A checklist summarizing these recommendations and the monitoring and response framework for improving air quality in ice arenas can be found in appendix A.

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APPENDIX A: CHECKLIST FOR IMPROVING AIR QUALITY IN ICE ARENAS

Implementing best practices for improving air quality in an ice arena is a multistep process that should consider equipment options, use and maintenance, emission source reduction and removal actions, regular air monitoring, and actions in the event of pollutant concentrations exceeding recommended health-based exposure limits. Outlined below are recommended strategies for maintaining and improving air quality in ice arenas, that should be implemented if possible, to help protect users' health.

ICE RESURFACING AND EDGING

- ❍ Use electric resurfacers and edgers, where possible, to eliminate the main sources of CO and NO_2.
- ❍ Avoid gasoline- and diesel-powered resurfacers and edgers; propane and natural gas are preferred fuel alternatives.
- ❍ Fit ice resurfacers with internal combustion engines with three-way catalytic converters.

EQUIPMENT OPERATION AND MAINTENANCE

- ❍ Follow regular maintenance schedules for ice resurfacers, edgers, heaters located in spectator areas, and all other fuel-burning equipment, as per manufacturer's instructions.
- ❍ Warm up resurfacers outdoors or in a dedicated room with a CO alarm and increased ventilation for five minutes prior to use.
- ❍ Extend the exhaust pipe of the ice resurfacer to above the protective barrier surrounding the ice surface.
- ❍ Limit the number of resurfacings, where possible.
- ❍ Schedule maintenance when there is reduced public activity in the arena.
- ❍ Eliminate vehicle idling near entrances or air intakes of the arena.

VENTILATION WITH FRESH AIR AND IMPROVEMENT OF AIR CIRCULATION

- ❍ Operate ventilation system for at least 10 minutes per hour of operation, ideally continuously during resurfacing.
- ❍ Implement two-hour continuous ventilation "flush-outs" overnight to remove pollutants accumulated during daily operations.
- ❍ Ensure there is extra ventilation on days where there are increased resurfacings.
- ❍ Consider installing an automated ventilation system with programmable timers to schedule daily ventilation events.
- ❍ Open gates around the ice surface during resurfacing to increase air circulation.
- ❍ If available, run ceiling fans continuously to increase air circulation and updraft, ideally with the fans connected to the arena light switches.

AIR POLLUTANT MONITORING

- ❍ Collect samples near centre ice (such as in the timekeeper's box, provided that it is not closed off from the ice surface) and at breathing height (approximately one metre).
- ❍ Install and maintain CO alarms throughout the arena and check regularly. Consider choosing an alarm with a digital low-level CO display.
- ❍ Consider using continuous monitoring systems for CO and NO_2, and checking and recording levels daily, at a minimum.
- ❍ Where possible, couple continuous air monitoring systems with mechanical ventilation to trigger the ventilation system when pollutant concentrations reach action levels.
- ❍ If continuous monitoring is not available, conduct one-hour average CO and NO_2 monitoring on a weekly basis at a minimum, on a day and time when there are the most resurfacing events. Levels should be documented.
- ❍ Monitor on days with the most resurfacings, during the evening or near the end of daily operations.
- ❍ Ensure monitoring equipment meet the resolution, range, and precision specified in the table below.
- ❍ Follow manufacturer's instructions for maintenance and calibration of air monitoring equipment.
- ❍ Document and store monitoring results.

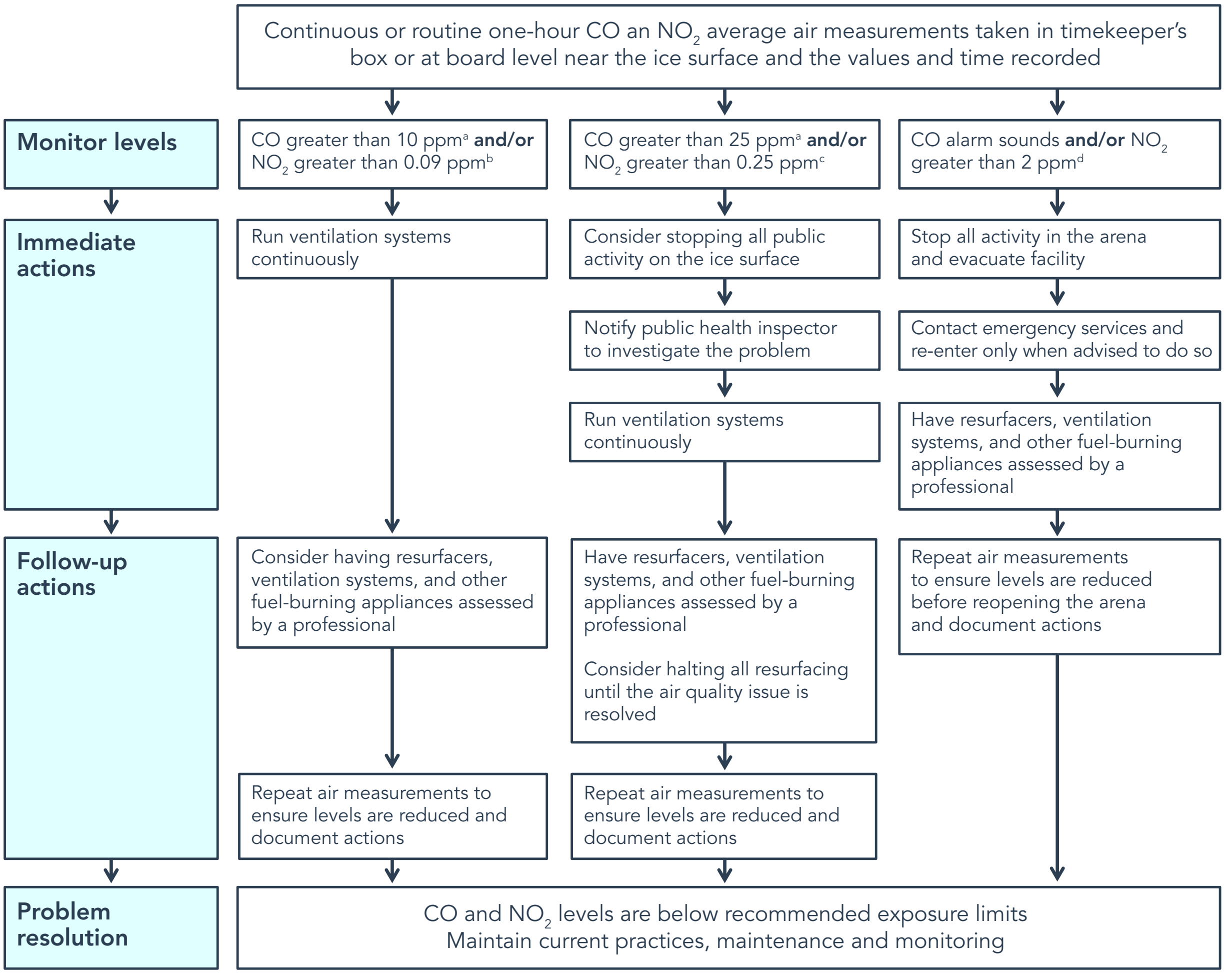
Minimum pollutant monitor requirements for air quality sampling in ice arenas

Pollutant	Resolution	Range	Precision
CO	1 ppm	0–200 ppm	± 5%
NO_2	0.02 ppm	0–10 ppm	± 5%

POLLUTANT LEVELS AND RESPONSE ACTIONS TO ELEVATED CO AND NO_2 LEVELS

- ❍ Arenas should attempt to keep pollutant levels as low as possible using the guidance outlined in this checklist.
- ❍ Immediate actions outlined in the figure below should be followed when CO and NO_2 levels exceed 25 ppm and 0.25 ppm, respectively.
- ❍ Actions taken to reduce levels should be appropriately documented.

RESPONSE ACTIONS TO ELEVATED CO AND NO_2 LEVELS IN ICE ARENAS



[a]Health Canada 2010; [b]Health Canada 2015; [c]Health Canada 1987; [d]Beausoleil et al. 2014