SURVEY REPORT: EVALUATION OF ICE RESURFACING EQUIPMENT AND VENTILATION IN AN INDOOR ICE ARENA

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FACILITY SURVEYED	Lehigh Valley Ice Arena Whitehall, PA
SIC CODE	N/A
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BACKGROUND

On October 17-18, 2002, in response to a request for technical assistance from the Pennsylvania Department of Health, engineers from the Engineering Control Technology Branch, Division of Applied Research and Technology, conducted an investigation of health complaints at an ice rink in Whitehall Pennsylvania The complaints, documented in a National Center for Environmental Health (NCEH) report, were centered on carbon monoxide and nitrogen dioxide emissions from the ice re-surfacing equipment The NCEH report, which will include epidemiological data, has not been finalized at the time of this writing This report focuses on the assessments of the building ventilation systems and some limited evaluations of the ice re-surfacing equipment This study was conducted in conjunction with the efforts of NCEH epidemiologists and Pennsylvania Department of Health industrial hygienists

Incident Description
On Sunday, September 29, 2002, following a college hockey game, a number of players reported a variety of health effects Several individuals required hospitalization The symptoms, while varied, were consistent with exposure to carbon monoxide and nitrogen dioxide Once the effects were reported to the facility management, subsequent activities at the facility were canceled for the day and the malfunctioning ice resurfacing equipment was immediately removed from any operations

According to ice rink personnel, because of the concern about carbon monoxide and nitrogen dioxide, one of the ice re-surfacing machines was inspected by a Zamboni company representative and third party service technician on October 2, 2002 The inspection found that this machine, a propane-fired Zamboni model, was not properly operating on all four cylinders Eight days prior to the incident, the machine had been serviced by the same third party service company, with an adjustment of the valves On October 4, 2002, industrial hygienists from the Pennsylvania Department of Health along with a team from the Pennsylvania Department of Environmental Protection, conducted air sampling in the arena during the re-surfacing of the ice For this test, a second ice re-surfacing machine (also propane powered) was operated Direct reading instrumentation was used to measure carbon monoxide and oxides of nitrogen On October 7, 2002, these tests were repeated with the first ice re-surfacing machine, the one used on the day of the incident

Nitrogen Dioxide Exposure NO_2
NO_2 is a lethal gas that is produced when fuels such as gasoline or propane are burned It is one of many chemicals found in engine exhaust resulting from incomplete combustion Nitrogen dioxide is a yellowish-brown liquid or reddish-brown gas (above 70°F) with a pungent, acrid odor (NIOSH 2002) Breathing low levels of nitrogen dioxide can cause a slight cough, mild fatigue, and nausea Eye, nose, and throat irritation are also common symptoms At high concentrations, NO_2 can cause severe coughing, choking, headache, nausea, abdominal pain, and shortness of breath If exposure is severe, symptoms may continue after the exposure has ended, causing difficulty breathing for weeks

Nitric Oxide Exposure (NO)
Oxides of nitrogen (NO_x) include nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), di-nitrogen tetroxide (N_2O_4), as well as other possible combinations Nitric oxide is a colorless gas that targets the eyes, skin, respiratory system, blood, and central nervous system

Carbon Monoxide Exposure (CO)
CO is a lethal poison that is produced when fuels such as gasoline or propane are burned Like NO_2 it is one of many chemicals found in engine exhaust resulting from incomplete combustion Because CO is a colorless, odorless, and tasteless gas, an exposed person can be overcome without warning The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, or nausea Symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered If the exposure level is high, loss of consciousness may occur without other symptoms Coma or death may occur if high exposures continue (NIOSH 1972, NIOSH 1977, NIOSH 1979) The display of symptoms varies widely from individual to individual, and may occur sooner in susceptible individuals such as young or elderly people, people with preexisting lung or heart disease, or those living at high altitudes (Proctor, Hughes et al 1988, ACGIH 2002, NIOSH 2000)

Exposure to CO limits the ability of the blood to carry oxygen to the tissues by binding with the hemoglobin to form carboxyhemoglobin (COHb) Blood has an estimated 210-250 times greater affinity for CO than oxygen, thus the presence of CO in the blood can interfere with oxygen uptake and delivery to the body (Forbes, Sargent et al 1945)

Although NIOSH typically focuses on occupational safety and health issues, the Institute is a public health agency, and cannot ignore the overlapping exposure concerns generated from the use of internal-combustion powered ice resurfacing equipment in an indoor environment The general public in an ice rink facility may range from infants to the elderly, be in various states of health and susceptibility, and be functioning at a higher rate of metabolism because of increased physical activity The occupational exposure limits noted below should not be used for interpreting general population exposures, they are presented to illustrate the toxic nature of these contaminants These exposure criteria were developed for employees and do not provide the same degree of protection for the general public as they do for the healthy worker population

Exposure Criteria for CO
The NIOSH Recommended Exposure Limit (REL) for occupational exposures to CO gas in air is 35 parts per million (ppm) for full shift time-weighted average (TWA) exposure, and a ceiling limit of 200 ppm, which should never be exceeded (CDC 1988, CFR 1997) The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5% (Kales 1993) NIOSH has established the immediately dangerous to life and health (IDLH) value for CO as 1,200 ppm (NIOSH 2000) The American Conference of Governmental Industrial Hygienists' (ACGIH®) recommends an 8-hour TWA threshold limit values (TLVs®) for occupational exposures of 25 ppm (ACGIH 2002) and recommends against exposures above 125 ppm for more than 30 minutes during a workday The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for CO is 50 ppm for an 8-hour TWA exposure (CFR 1997)

The U S Environmental Protection Agency (EPA) has promulgated a National Ambient Air Quality Standard (NAAQS) for CO This standard requires that ambient air contain no more than 9 ppm CO for an 8-hour TWA, and 35 ppm for a 1-hour average (EPA 1991) The NAAQS for CO was established to protect "the most sensitive members of the general population "

Exposure Criteria for NO_2

The NIOSH Recommended Exposure Limit (REL) for occupational exposures to NO_2 gas in air is 1 part per million (ppm) for a short-term exposure limit (STEL), which is a 15-minute time weighted average that should not be exceeded at any time during a workday (NIOSH 2002) NIOSH has established the immediately dangerous to life and health (IDLH) value for NO_2 as 20 ppm (NIOSH 2002) The American Conference of Governmental Industrial Hygienists' (ACGIH®) recommends an 8-hour TWA threshold limit values (TLVs®) for occupational exposures of 3 ppm (ACGIH 2002) and has a short-term exposure level (STEL) of 5 ppm The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for NO_2 is 1 ppm as a short-term exposure limit (NIOSH 2002)

Exposure Criteria for Nitric Oxide (NO)

The NIOSH Recommended Exposure Limit (REL) for occupational exposures to NO gas in air is 25 parts per million (ppm) for full shift time-weighted average (TWA) exposure (NIOSH 2002) NIOSH has established the immediately dangerous to life and health (IDLH) value for NO as 100 ppm (NIOSH 2002) The American Conference of Governmental Industrial Hygienists' (ACGIH®) recommends an 8-hour TWA threshold limit values (TLVs®) for occupational exposures of 25 ppm (ACGIH 2002) The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for NO is 25 ppm for an 8-hour TWA exposure (NIOSH 2002)

Massachusetts Requirements to Maintain Air Quality in Indoor Skating Rinks

The Massachusetts Bureau of Environmental Health Assessment set air action levels for carbon monoxide and nitrogen dioxide for indoor skating rinks in Massachusetts Any single air concentration exceeding thirty (30) parts per million (ppm) for carbon monoxide or 0 5 ppm for nitrogen dioxide is referred to as the correction air level and requires corrective measures listed in the Code of Massachusetts Regulations under 105 CMR 645 009 to reduce concentrations Notification air levels include any single air sample concentration exceeding 60 parts per million (ppm) or 6 consecutive air samples which exceed 30 parts per million (ppm) for carbon monoxide or a single air sample concentration exceeding 1 part per million (ppm) for nitrogen dioxide Notification air levels must be reported to the fire department within one hour The local board of health and the Massachusetts Bureau of Environmental Health Assessment must be notified within twenty-four hours Single air concentrations exceeding one hundred twenty-five (125) parts per million (ppm) for carbon monoxide or 2 ppm for nitrogen dioxide, referred to as evacuation air levels, require the facility to be evacuated Under 105 CMR 675 011 the local fire department must be contacted as soon as possible, the local board of health must be contacted upon evacuation, and the Massachusetts Bureau of Environmental Health Assessment must be contacted within 2 hours of evacuation

METHODS

A ventilation analysis was performed on the Valley Rink at the Lehigh Valley Ice Arena Complex in Whitehall, Pennsylvania A diagram of the facility (Figure 1) shows approximate locations of supply and exhaust air vents in each room Direct reading air velocity measurements were taken from the supply and exhaust vents in each room using a hot wire anemometer Air velocity measurements were also taken on the filter slot of the air handling unit Measurements were taken across the face of the vent at eight locations in a grid pattern The mean of the eight air velocity measurements was calculated and multiplied by the cross sectional area of the vent to obtain total volumetric flow of air through the vent in cubic feet per minute

Smoke was released in each locker room to help determine air flow patterns Smoke was also released in the hockey rink to help determine air movement Pictures from the smoke machine taken approximately twenty minutes after the release of smoke are shown in Figure 2 Temperature measurements were taken above the ice at 1 inch, and at 1 foot increments up to 5 feet

Due to health and safety considerations during the NIOSH evaluation, ice-resurfacing equipment was not tested in a manner which attempted to recreate the incident that occurred on Sunday, September 29, 2002, that is, the Valley ice-resurfacing machine was not operated within the Valley Arena and NIOSH did not conduct tests monitoring air quality at the breathing zone level Stationary emissions tests were performed on three ice-resurfacing machines using a gas emissions analyzer The sensor for the gas emissions analyzer was placed approximately 10 inches into the tail pipe of each ice-resurfacing machine Data was collected for cold start idle, operating speeds of approximately 2500 rpm, and idle with the engine warm

Micromanometer measurements were taken in each room to determine pressurization These measurements were taken in the locker rooms and restrooms with the exhaust ventilation system off Pressure measurements were taken again only in the locker rooms with the exhaust system on The exhaust system was not operational in the men's and women's restrooms An additional measurement was recorded in locker room 1 while holding the door shut with the exhaust system turned on

Description of Evaluation Equipment

Emissions data was collected from three ice resurfacing machines using a Ferret Instrument 5-gas emissions analyzer The five gas analyzer measures carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons, oxygen, air fuel ratio (AFR), and nitrogen oxides (NO_x) All measurements are expressed as percentages except hydrocarbons and NO_x which is ppm

Air flow was measured using a VelociCalc Plus Model 8388 air velocity meter (TSI Inc , St Paul, MN) Air velocity readings were collected at the face of each vent Estimates of total flow rates were obtained by averaging the air velocity measurements and multiplying by the cross-sectional area of the vent where the air velocity measurements were taken

Facility Description

The Lehigh Valley complex consists of two separate buildings The building nearest the front of the property is referred to as the Lehigh Rink and the building behind it is referred to as the Valley Rink Each building has a separate machine used for resurfacing of the ice The Valley Ice-Resurfacing Machine was used in the Valley Rink, and the Lehigh Ice-Resurfacing Machine is used in the Lehigh Rink A leased ice resurfacing machine is used at both rinks The ice rink building under evaluation is referred to as the Valley Rink and was built in 1997 Building features include one ice rink, an upstairs office and foyer area, a spectator balcony, four locker rooms, a first aid room, a service room, showers, men's and women's restrooms, and a compressor resurfacing room According to the owner, the Valley Rink covers 20,000 sq ft with a maximum occupancy of 400 people The volume of the ice arena is approximately 660,000 cubic feet The building diagram (Figure 1) is not to scale

At opposite corners of the ice rink approximately 12 feet above the floor are two dehumidifier units The dehumidifier ductwork extends up to the highest point of the ceiling behind each goal pulling air from the ceiling and returning dehumidified air in the corner at the unit The room containing the ice hockey rink did not have ventilation or air movement other than the dehumidifier units shown on the diagram in Figure 1

The compressor/re-surfacing room houses a compressor, equipment for the under-ice refrigeration system, four water heaters, an air handing unit, and a location for storage of an ice re-surfacing machine Adjacent to the compressor/re-surfacing room is locker room four On Wednesday, October 2, 2002, a spill of ethylene glycol was discovered on the floor of locker room four stretching from under the compressor/resurfacing room wall to a few feet before the drain in the center of the room Next to locker room four separated by showers is locker room three Locker room two is in the corner and shares a wall with locker room three and a wall with a shower room that separates locker room one from locker room two The four locker rooms are supplied with conditioned air from the air handing unit located in the compressor/re-surfacing room This air handling unit had a dimensionally incorrect filter installed Because of the size of the filter, the filter access cover was not installed, and the unit was drawing a significant volume of air from the compressor/re-surfacing room Locker room one is the greatest distance from the supply air, while locker room four is on the opposite side of the wall from the air handling unit Air is exhausted from all four locker rooms by means of an exhaust system located outside locker room one

On the other side of the stairs from locker room one are the women's and men's restrooms, first aid room, a changing room, and a service room The first aid room, changing room, and service room each include a wall unit for air handling Located in the women's restroom is the air handing unit that supplies air only to the women's and men's restrooms Exhaust fan 2 located in the men's restroom connects to ductwork through the men's and women's restrooms and is a separate system from the exhaust system that services the locker rooms Upon inspection, exhaust fan 2 was not functional

Figure 1: Diagram of Valley Ice Rink Facility

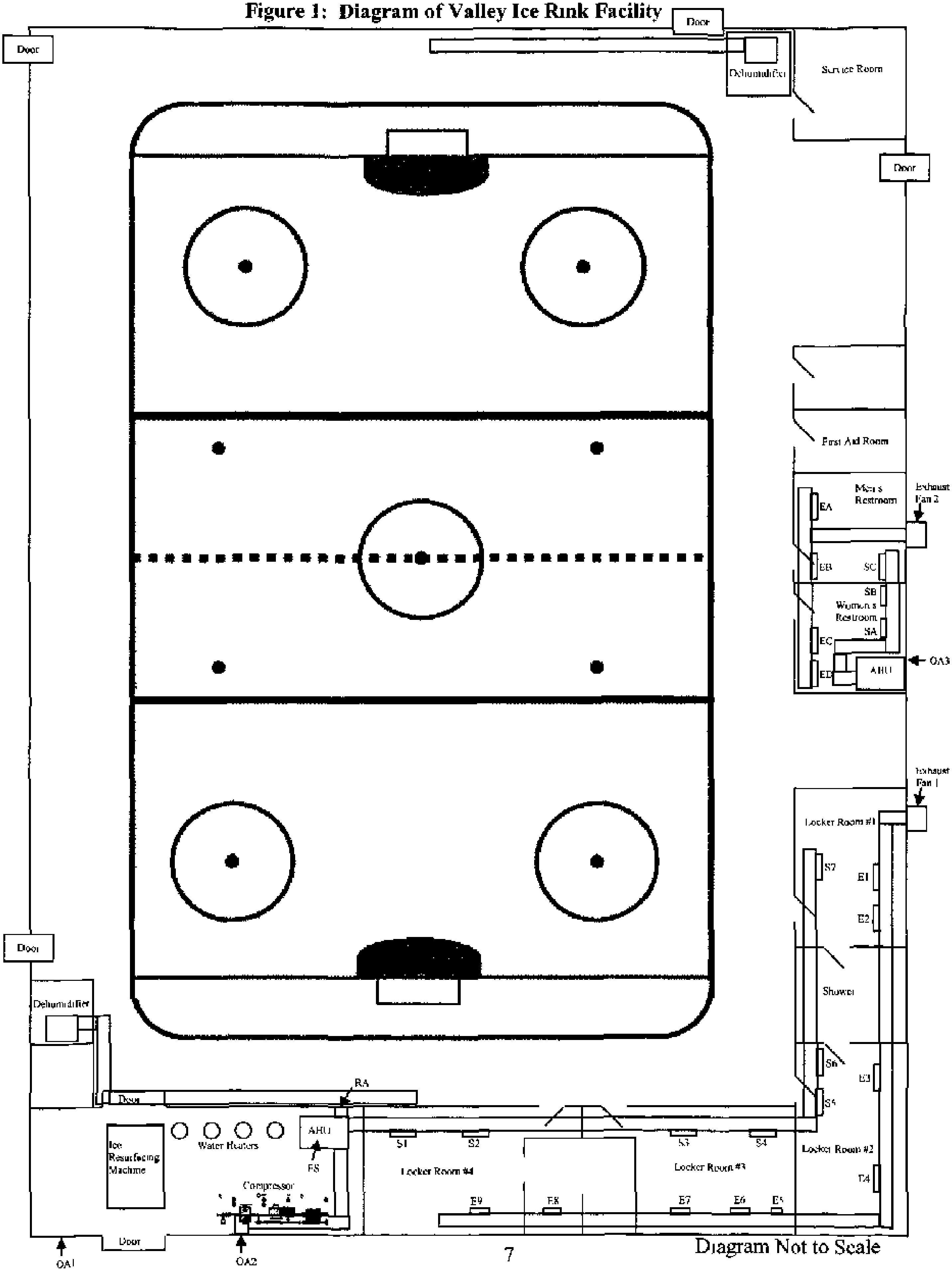


Diagram Not to Scale

Figure 2: Picture of Smoke Release

RESULTS

Micromanometer measurements taken to determine pressurization of each locker room are presented in Table 1 The pressure in locker room 1 taken while holding the locker room door shut with the exhaust system turned on was -0 030 inches of water With the exhaust system turned on, pressure was positive in locker room 4 closest to the air handling unit and negative in locker room 1 near the exhaust unit With the exhaust system turned off, pressure was positive in all rooms The calculated values (Table 2) reveal the approximate volume of air in cubic feet per minute passing through the supply and exhaust vents in each room Temperature measurements in the ice arena (Table 3) were made at several locations above the ice

The ice-resurfacing machines were tested during idle and at rpm levels similar to operating speeds Graphs 1-3 show levels of carbon monoxide measured from the exhaust to be higher for each ice-resurfacing machine while engine speeds were at idle Tests performed on the leased machine with an exhaust gas purifier revealed that at 2700 rpm the percentage of carbon monoxide in the exhaust was close to zero However, even with the exhaust gas purifier in place, CO levels were measured to be extremely high when the engine was at idle speed

Graph 1 displays the emissions results for the machine used on Sunday September 29, 2002 Values on all graphs for IDLH are for concentrations in air at or near the breathing zone, while the values for CO shown on the graph were measured at the source with a sensor in the exhaust pipe Data from the manufacturer was not available to compare emissions from ice-resurfacing equipment tested with the emissions from normally functioning ice-resurfacing equipment

A summary of the emissions data collected from the three ice resurfacing machines using a Ferret Instrument 5-gas emissions analyzer can be seen in Tables 4-6 During cold start idle, peak and mean concentrations for both CO and NO_x were highest for the Valley machine At operational speeds of 2500 rpm, peak concentrations of CO were highest for the Valley machine, while mean CO values were highest for the Lehigh machine Peak values for NO_x at 2500 rpm were highest for the leased machine while mean NO_x values were highest for the Valley machine Peak and mean CO values were highest for the leased machine during idle with the engine warm Peak and mean concentrations for NO_x were highest for the Valley machine during idle with the engine warm Summary statistics results reveal that mean concentrations for Nitric Oxides were highest in all three tests for the Valley machine

Storage for the ice-resurfacing machine servicing the Valley Ice Rink is located in the same room as the air handling unit If any of the machines tested were left to warm up in the compressor/resurfacing room with the garage door shut, it is very possible that concentrations of combustion gases in the room could reach unacceptable levels

Table 1· Room Pressurization Measurements

Location	Pressure (inches of water)	
	Exhaust ON	*Exhaust OFF*
Locker Room 1	-0 024	+0 014
Locker Room 2	-0 004	+0 016
Locker Room 3	0	+0 028
Locker Room 4	+0 004	+0 022
Women's Restroom		+0 032
Men's Restroom		+0 025

Table 2: Flow of Supply and Exhaust Air

Location	Labels on Diagram	Flow (cfm)
Airflow through filter slot in AHU	FS	300
End of Rink return air	RA	280
Compressor/resurfacing room vent to outside	OA2	745
Supply 1	S1	218
Supply 2	S2	57
Supply 3	S3	123
Supply 4	S4	211
Supply 5	S5	154
Supply 6	S6	204
Supply 7	S7	188
Exhaust 1	E1	238
Exhaust 2	E2	167
Exhaust 3	E3	59
Exhaust 4	E4	149
Exhaust 5	E5	35
Exhaust 6	E6	65
Exhaust 7	E7	50
Exhaust 8	E8	20
Exhaust 9	E9	72
Supply A	SA	317
Supply B	SB	756
Supply C	SC	619
Exhaust A	EA	23
Exhaust B	EB	30
Exhaust C	EC	71
Exhaust D	ED	41
Intake for AHU in restrooms	OA3	1136

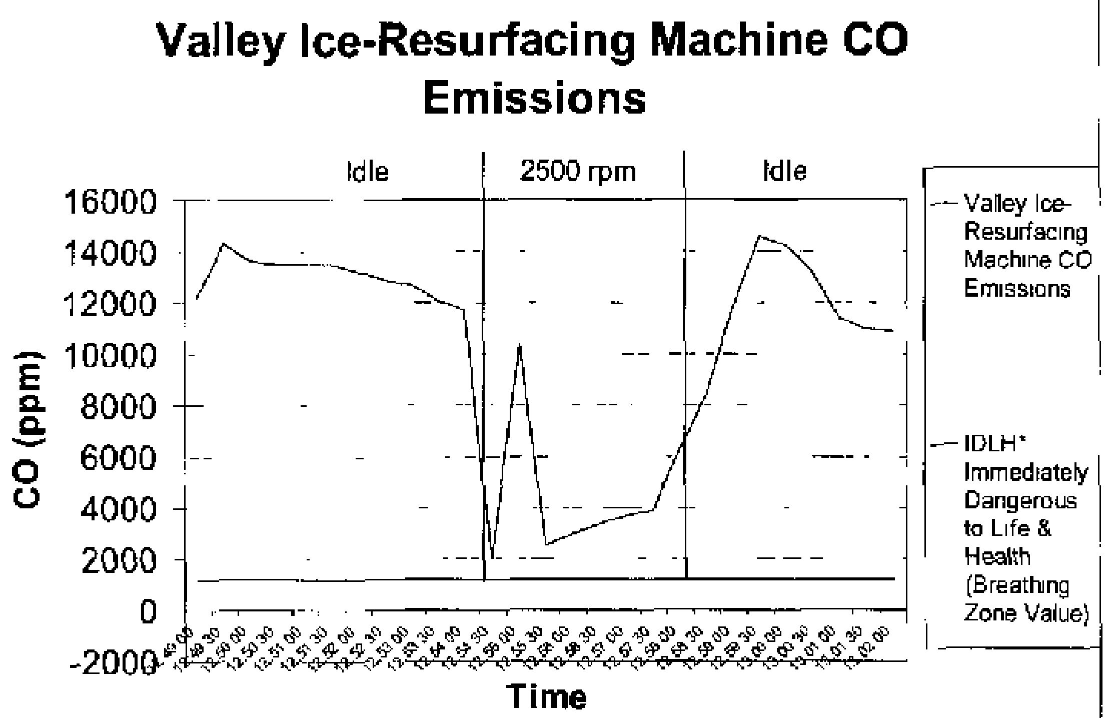
Table 3: Temperature Measurements Above the Ice

Height (inches)	Temperature (°F)
1	25 7
12	30 1
24	31 2
36	31 8
48	32 4
60	33 4

Engine Description

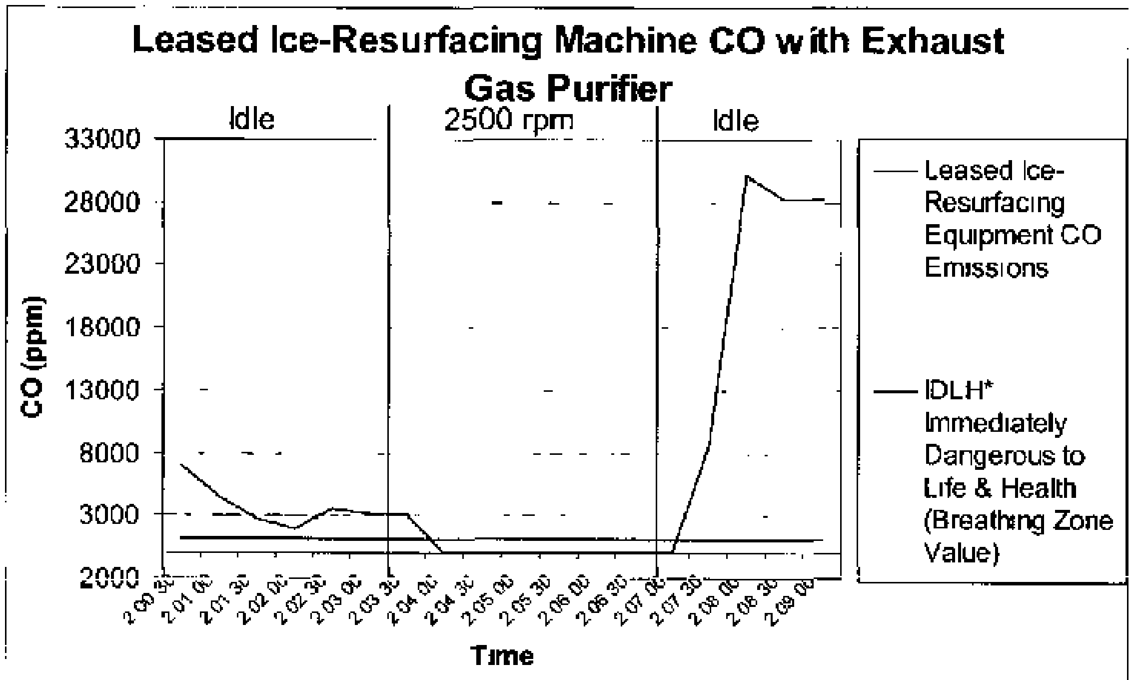
Engine Make	126 A
Engine Type	4 cyl, 4 stroke, gasoline converted to propane
Bore	3 36 inches
Stroke	2 72 inches
Displacement	96 6 cubic inches
Compression Ratio	7 5 1
Gross HP (SAE)	53 at 3600 rpm
Gross Torque (SAE)	78 94 ft lb at 2200 rpm
Valve Clearance (with engine cold)	intake & exhaust 004 inches
Fuel Rating	Regular
Idle Speed	900
Ignition	
Voltage	12 V
Battery	
Firing Order	

Graph 1 Valley Ice-Resurfacing Machine Carbon Monoxide Emissions (measured at the tailpipe)



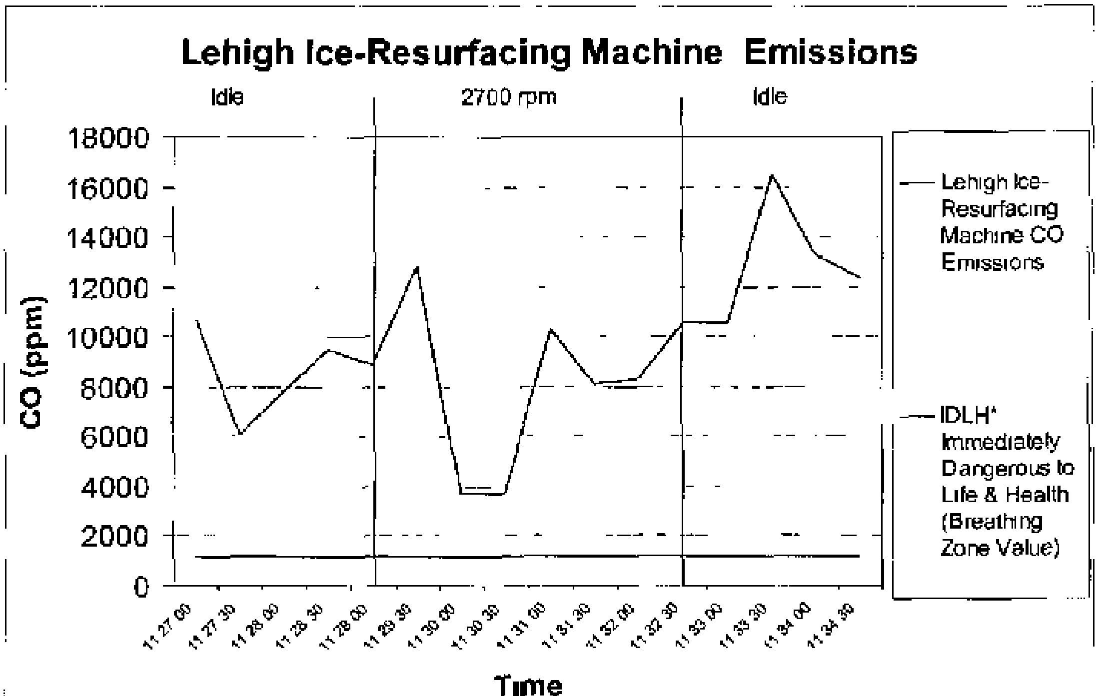
*IDLH values shown on the graph are not meant to represent acceptable emission test standards They are provided only to put the emission data into perspective

Graph 2 Leased Ice-Resurfacing Machine Carbon Monoxide Emissions (measured at the tailpipe)



IDLH values shown on the graph are not meant to represent acceptable emission test standards They are provided only to put the emission data into perspective

Graph 3 Lehigh Ice-Resurfacing Machine Carbon Monoxide Emissions (measured at the tailpipe)



*IDLH values shown on the graph are not meant to represent acceptable emission test standards They are provided only to put the emission data into perspective

Table 4. Ice Resurfacing Machines (Cold Start Idle) Comparison of 5-gas Emissions Analyzer Data

	Valley Ice-Resurfacing Machine	Leased Ice-Resurfacing Machine	Lehigh Rink Ice-Resurfacing Machine
Hydrocarbons (ppm)	Mean=700 Std Dev =11 n=10 Peak=713	Mean=53 Std Dev =27 n=6 Peak=89	Mean=30 5 Std Dev =8 55 n=6 Peak=47
Carbon Monoxide (ppm)	Mean=13,150 Std Dev =680 n=10 Peak=14,300	Mean=3,817 Std Dev =1,786 n=6 Peak=7,000	Mean=9,300 Std Dev =2,319 n=6 Peak= 12,800
Carbon Dioxide (%)	Mean=7 34 Std Dev =0 13 n=10 Peak=7 5	Mean=15 Std Dev = 11 n=6 Peak=15 1	Mean=11 4 Std Dev =0 25 n=6 Peak=11 7
Oxygen (%)	Mean=9 63 Std Dev = 13 n=10 Peak=9 9	Mean=0 Std Dev =0 n=6 Peak=0	Mean=4 38 Std Dev =0 27 n=6 Peak=4 8
Nitric Oxides (ppm)	Mean=424 Std Dev=46 n=10 Peak=519	Mean=158 Std Dev=64 n=6 Peak=220	Mean=45 5 Std Dev=20 11 n=6 Peak=79

Table 5· Ice Resurfacing Machines (2500-2700 rpm) Comparison of 5-gas Emissions Analyzer Data			
	Valley Ice-Resurfacing Machine	**Leased Ice-Resurfacing Machine**	**Lehigh Rink Ice-Resurfacing Machine**
Hydrocarbons (ppm)	Mean=478 Std Dev =82 n=9 Peak=679	Mean=49 Std Dev =7 5 n=8 Peak=62	Mean=15 7 Std Dev =5 24 n=6 Peak=24
Carbon Monoxide (ppm)	Mean=5,200 Std Dev =3,533 n=9 Peak=11,700	Mean=425 Std Dev =1,122 n=8 Peak=3200	Mean=7,450 Std Dev =3,076 n=6 Peak= 10,600
Carbon Dioxide (%)	Mean=11 58 Std Dev =1 3 n=9 Peak=12 3	Mean=14 Std Dev =0 44 n=8 Peak=15	Mean=14 12 Std Dev =0 19 n=6 Peak=14 4
Oxygen (%)	Mean=4 53 Std Dev =1 29 n=9 Peak=7 8	Mean=1 5 Std Dev =0 7 n=8 Peak=2 1	Mean=0 88 Std Dev =0 04 n=6 Peak=0 90
Nitric Oxides (ppm)	Mean=2,351 Std Dev=267 n=9 Peak=2,562	Mean=2,264 Std Dev=884 n=8 Peak=2,816	Mean=954 Std Dev=93 n=6 Peak=1,110

Table 6: Ice Resurfacing Machines (Idle with Engine Warm) Comparison of 5-gas Emissions Analyzer Data

	Valley Ice-Resurfacing Machine	Leased Ice-Resurfacing Machine	Lehigh Rink Ice-Resurfacing Machine
Hydrocarbons (ppm)	Mean=634 6 Std Dev =88 n=8 Peak=701	Mean=112 Std Dev =46 n=4 Peak=137	Mean=0 Std Dev =0 n=4 Peak=0
Carbon Monoxide (ppm)	Mean=11,938 Std Dev =2021 n=8 Peak=14,600	Mean=23,825 Std Dev =10,256 n=4 Peak=30,200	Mean=13,200 Std Dev =2,470 n=4 Peak=16,500
Carbon Dioxide (%)	Mean=8 51 Std Dev =1 21 n=8 Peak=11 5	Mean=13 3 Std Dev =0 13 n=4 Peak=13 5	Mean=12 1 Std Dev =0 35 n=4 Peak=12 6
Oxygen (%)	Mean=8 19 Std Dev =1 51 n=8 Peak=9	Mean=0 15 Std Dev =0 24 n=4 Peak=0 5	Mean=3 05 Std Dev =0 37 n=4 Peak=3 3
Nitric Oxides (ppm)	Mean=530 Std Dev=222 n=8 Peak=1,077	Mean=190 Std Dev=213 n=4 Peak=508	Mean=101 Std Dev=73 n=4 Peak=211

DISCUSSION

Problems with air pollution in indoor ice arenas have previously been documented (Brauer M, Spengler JD 1994, LeeK, Yanagisawa Y, Spengler JD, et al 1994, Pribyl CR, Racca J 1996, Smith W, Anderson T, Anerson HA, et al 1992) The main toxic agent has been carbon monoxide (CO), in recent years, investigators have also described toxic effects resulting from nitrogen dioxide (NO_2) exposure These problems have typically been traced to malfunctioning ice-resurfacing machines in combination with inadequate ventilation The hazard of exposure to poisonous gases from internal combustion powered ice-resurfacing equipment in indoor ice arenas is a potential public health problem in Pennsylvania and in many other states in which ice hockey and other indoor ice-skating activities are popular

RECOMMENDATIONS

1) The safest solution for preventing poisoning from carbon monoxide and nitrogen dioxide in indoor ice arenas would be to replace ice-resurfacing equipment powered by gasoline or propane with electric equipment However, this solution may not be economically viable in all situations and creates a potential hazard from hydrogen gas produced from recharging the batteries Cost advantages may exist when considering ventilating a small battery charging room as compared to ventilation of propane emissions in an ice arena If possible, the battery charging room should not be located in the same room as the air handling unit
2) If propane fueled ice-resurfacing equipment is used, it is essential that the machine is operating properly and is fitted with a catalytic converter, exhaust gas purifier or some other emission control device Regular emissions testing should be performed to verify that the catalytic converter is operating efficiently Under no circumstance should a propane or gasoline powered ice-resurfacing machine idle indoors to warm up while exhausting inside of a building
3) The machine should be configured with a vertical exhaust stack that exhausts the gas as high as reasonable possible Gas or propane ice-resurfacing equipment fitted with a catalytic converter and exhaust stack should warm up outside for a minimum of 10 minutes to allow the exhaust gas purifier to work properly
4) If conditions outdoors do not allow for warm-up of the machine, a properly designed hose exhaust system to ventilate the combustion gases from the stack to a location outside of the facility should be used Any ventilation hose system should fit tightly around the exhaust stack to prevent leaks The system should also be powered by a fan or any means of pulling the contaminant out of the hose to the exterior of the building away from any air intake For convenience in this facility, the hose could run through the ceiling of the resurfacing room at the location where the ice-resurfacing machine is parked
5) Proper sized filters should be installed in all air handing units in the facility Before operation of an air handling unit, the access cover should be replaced over the slot where the filter has been inserted

6) In a room with high concentrations of combustion gases, contaminated air can still enter the air handling unit even when the system is properly maintained To prevent exhaust gas from entering this air handling unit, it should be relocated to another area (locker room 4, for example) The return air and outside air ductwork should also be moved to prevent any leaks in the system from pulling in air from the compressor/resurfacing room Any holes in the wall between the compressor/resurfacing room and locker room 4 should also be sealed
7) Personnel must regularly monitor indoor air quality during and after every ice resurfacing to avoid situations of exposure to toxic levels of combustion gases With regard to the risk of carbon monoxide and nitrogen dioxide exposure, air-quality regulations for indoor ice arenas should be developed
8) For ventilation of the ice arena, air should be exhausted at the ceiling and make-up air should be brought in from outdoors through a dehumidifier unit A dedicated dehumidifier unit is recommended for make-up air conditioning to provide better humidity control for the rink than a combined (make-up and return air) system Currently the dehumidifier units return dehumidifier air at 10 to 12 feet above the floor In order to allow for proper mixing of fresh air with exhaust gas, we recommend lowering the return of dehumidified air as close to the floor as possible
9) Proper amounts of outdoor air should be brought in to dilute the poisonous gas to favorable levels Ventilation systems should be properly maintained and sufficient to provide air movement preventing the accumulation of hazardous gases

The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 62-2001 prescribes a supply rate of 0 50 cfm/ft^2 in ice arena playing areas for acceptable outdoor air required to have acceptable indoor air quality A typical hockey rink 200 feet in length by 85 feet wide would require 8,500 cubic feet per minute of outdoor air to meet the ASHRAE ventilation requirement The ASHRAE standard also prescribes 15 cubic feet per minute per person for spectator areas of sports facilities The maximum occupancy as provided by the owner was assumed to be approximately 400 people and would require the capacity for an additional 6,000 cubic feet per minute of outdoor air Given the ASHRAE standard for spectator areas and playing areas, the ice arena system should have capacity to ventilate 14,500 cubic feet per minute of outdoor air to meet indoor air quality requirements when the facility is in use at maximum occupancy The room containing the ice hockey rink did not have ventilation or air movement other than the dehumidifier units shown on the diagram in Figure 1 Any changes to the facility should meet applicable state and local codes and regulations Depending on the characteristics of the ice-resurfacing equipment, this exhaust volume may be sufficient to control emissions from internal combustion powered equipment Equipment to measure volume of emissions was not used during the NIOSH evaluation of the ice-resurfacing equipment Attempts were made to obtain exhaust volumes from the manufacturer of the ice-resurfacing machine used at the Valley Rink on Sunday September 29th After repeated requests, the manufacturer did not provide any information on volume of emissions for this specific piece of equipment Facility management should attempt to obtain this information (exhaust gas flow rates, concentration specifications, etc) from the manufacturer, and confirm that the 14,500 CFM exhaust will be adequate to control combustion gases NIOSH engineers can assist in this determination

CONCLUSIONS

From the limited evaluation of the ice resurfacing equipment and building ventilation system, NIOSH engineers determined that it was likely that people inside of the ice arena were overexposed to carbon monoxide and nitrogen oxides The final NCEH report will present the epidemiological study documenting the specific health affects of the exposed group The overexposures were likely a result of ice resurfacing equipment that was malfunctioning in combination with the specific design of the HVAC system serving the locker rooms and the lack of outside air supply to the rink in general

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