



INVESTIGATION REPORT

AMMONIA RELEASE — FERNIE MEMORIAL ARENA
DATE OF INCIDENT: OCTOBER 17, 2017

TECHNICAL SAFETY BC INCIDENT INVESTIGATION JURISDICTION AND ROLE

Technical Safety BC administers the *Safety Standards Act* (“Act”) on behalf of the Province of British Columbia¹. The Act and associated *Regulations* apply to the following products, operations and work associated with these products:

- (i) amusement devices;
- (ii) passenger ropeways;
- (iii) boilers and boiler systems;
- (iv) electrical equipment;
- (v) elevating devices and passenger conveyors;
- (vi) gas systems and equipment;
- (vii) pressure vessels;
- (viii) pressure piping;
- (ix) refrigeration systems and equipment; and
- (x) any other regulated product specified in the regulations.

The *Act* and Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation (“*Regulation*”) applies in respect of pressure vessels, pressure piping systems, fittings, refrigeration equipment and refrigeration plants in BC within the identified scope of the *Act* and *Regulation*. The refrigeration system, associated work and management of this refrigeration equipment at the Fernie Memorial Arena are subject to the *Act* and *Regulation*.

Incidents involving products or work subject to the *Act* are required to be reported in accordance with Section 36 of the *Act*. Technical Safety BC investigates these incidents in accordance with Section 37 of the *Act* and may appoint persons to assist with an investigation.

The role of Technical Safety BC with respect to the investigation of incidents is to understand relationships between incidents, equipment and work that are subject to the *Act*. It is our aim to learn from these investigations what happened to inform efforts to prevent the recurrence of similar incidents. Often, these investigations are conducted in cooperation with other agencies including fire departments, WorkSafeBC, law enforcement officials, and the Coroners Service.

This investigation report is issued by a Provincial Safety Manager and published in accordance with the *Act*. This report does not address issues of enforcement action taken under the *Act*. Any regulatory enforcement or compliance activities arising from this incident will be documented separately.

¹ Some municipalities administer portions of the Safety Standards Act. See www.technicalandsafetybc.ca for details.

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INCIDENT OVERVIEW

On October 16, 2017, the curling brine chiller at the Fernie Memorial Arena was put back into operation after a seasonal shutdown. During the shutdown and seasonal maintenance, ammonia had been detected in the curling brine system, indicating that the curling brine chiller was leaking.

At 3:53 a.m. on October 17, 2017, an ammonia alarm in the arena's mechanical room was triggered and the system was shut down. Between 9:15 a.m. and 9:38 a.m., rising pressure contained within the curling brine system led to the separation of a pipe coupling in the mechanical room. Upon separation of the coupling, an estimated 9 lb. of ammonia was rapidly released into the room followed by additional ammonia from the system. The atmosphere in the mechanical room may have reached or exceeded concentrations of 20,000 parts per million (ppm) of ammonia.

Ammonia odour was reported from nearby areas of the community between 9:40 a.m. and 1:20 p.m.. At 12:50 p.m., an electrician discovered a worker in the mechanical room, called 911, removed the person, and performed CPR until the arrival of the fire department.

A total of three people were found deceased in the mechanical room: the director of leisure services, the refrigeration operator, and a refrigeration mechanic.

Responders opened the emergency discharge valve and pressed the emergency stop for the ammonia system located on the exterior wall of the arena at 1:50 p.m.. Opening the discharge valve resulted in an estimated initial release of 55 lb. of ammonia into the atmosphere with approximately 632 lb. of ammonia from the system being slowly released during the subsequent days.

Due to the three fatalities, the ammonia release and the unknown amount of ammonia remaining in the arena on the day of the incident, the City of Fernie issued a local state of emergency and evacuated approximately 55 homes and 95 residents from the surrounding area. The evacuation order remained until October 22, 2017 and the local state of emergency remained in effect until October 24, 2017.

SITE DESCRIPTION

The Fernie Memorial Arena incorporated one refrigeration system that provided cooling for two coolant systems; one cooling the arena floor, and the other cooling the curling rink floor. The refrigerant used was ammonia and the coolant in both systems was a calcium chloride brine solution. Heat was exchanged between the brine systems and liquid ammonia within two-pass shell-and-tube heat exchangers, referred to as chillers. Details and diagrams of the facility and components related to the incident can be found in Appendix C.

The refrigeration system at the Fernie Memorial Arena had all of the operating permits required by Technical Safety BC at the time of the incident. There were no outstanding non-compliances from past inspections by Technical Safety BC that occurred in 2007, 2010, 2011, 2012 and 2014. Employees of the City of Fernie reported to have been working on or with the refrigeration system and their maintenance contractor were assessed to have met the training, qualification, and staffing requirements under the Act.

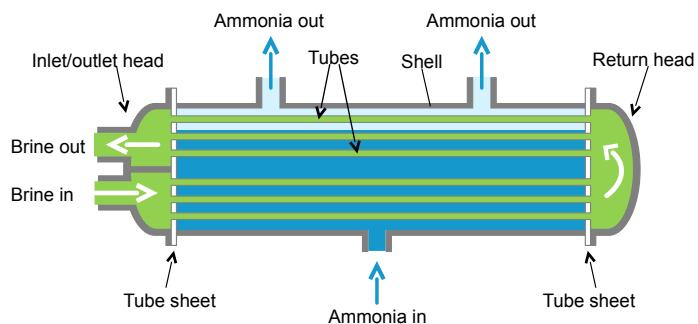


Figure 1: Generic diagram of a two-pass flooded chiller similar to that used at the Fernie Memorial Arena.

SUMMARY

On October 17, 2017 a rapid release of ammonia occurred within the mechanical room at the Fernie Memorial Arena and resulted in estimated concentrations of ammonia exceeding 20,000 ppm. Three people were in the room at the time of the release and were found deceased. The incident resulted in a local state of emergency for the community and an evacuation of the area around the arena.

Following the incident, Technical Safety BC conducted an investigation to determine factors that contributed to the ammonia release. The objective of the investigation was to identify causes and contributing factors to inform an understanding and management of safety risks associated with refrigeration systems.

The investigation identified three areas where evidence indicates causal and contributing factors leading to the incident and the subsequent impact to the arena and surrounding community:

- I. Failure of refrigeration system equipment
- II. Operational decisions that contributed to the incident
- III. Impact of inadequate ventilation and discharge systems following the incident

I. FAILURE OF REFRIGERATION SYSTEM EQUIPMENT

The investigation found that the ammonia release was initiated by a small hole within the curling system brine chiller caused by corrosion pitting at a carbon-steel tube welded seam. The corrosion process typically progresses with the operational use and age of equipment and can accelerate in areas containing defects that promote pitting. An estimated typical operational life-cycle of 20-25 years was identified for this type of chiller which was manufactured 31 years prior to the incident. The investigation did not find documentation indicating the exact start date of active service for the chiller.

Ammonia was detected within the brine system during maintenance and brine testing conducted as part of routine shut down procedures at the conclusion of the 2016/2017 operating season. After a summer shut down period, the curling refrigeration system was re-started on October 16, 2017. Ammonia released through the brine system led to an ammonia alarm at 3:53 a.m. on October 17, 2017.

In response to the ammonia leak, the brine system and curling chiller were isolated and the refrigeration and brine system were shut down. This impeded brine expansion and ventilation, as ammonia continued to leak into the brine over a five hour period. As the leak continued, the concentration of ammonia would have become higher close to the chiller and the hole in the tube. The likely effect within the brine system near the chiller was: an ammonia saturated volume of brine; a temperature increase from chemical reaction and heat absorption from the room; elevated pressure within the brine system and chiller; and a displaced volume of brine from ammonia being added to the saturated solution.

A brine system pipe segment was joined at two locations near the chiller by pipe couplings that were not supported to resist pipe movement from pressure or mechanically applied forces. The rising pressure within the brine system eventually exceeded the strength of the joint and one of the couplings separated. This separation suddenly depressurized the brine system and caused the ammonia in the system to rapidly expand, propelling the pipe contents into the room. As ammonia was released, it quickly expanded within the room, reaching estimated concentrations over 20,000 ppm.

II. OPERATIONAL DECISIONS THAT CONTRIBUTED TO THE INCIDENT

In October 2010, seven years prior to the incident, the City of Fernie received a recommendation from their maintenance contractor to replace the curling system brine chiller due to its age. Analysis of evidence gathered during the investigation identified a series of key decisions during this seven year period that contributed to the incident.

Potential influences of these decisions were identified, including:

- A. facility management and organizational priorities;
- B. failure to include safety risk criteria from aging infrastructure risk assessment;
- C. operational management structure;
- D. employee capacity and turnover;
- E. incomplete maintenance planning; and
- F. an industry practice of run-to-failure or run-past-failure for brine chillers.

The City of Fernie initially scheduled funding to replace the curling brine chiller for 2013. This funding was deferred to 2014 and then deleted from further financial planning. At the end of the 2016/2017 operating season, an ammonia leak was detected in the curling system, indicating a potential failure of the chiller. A decision was made to monitor the leaking chiller in the summer of 2017, followed by a decision to put the leaking chiller back into operation on October 16, 2017. Available evidence did not indicate that there was an awareness of any safety risk associated with the continued operation of the chiller by any parties involved.

The decision to operate the leaking chiller is pivotal in the development of the incident. Once the leaking chiller was put back into operation, additional actions and decisions were a response to cascading failures and were beyond the scope of training and situational awareness of those involved.

III. IMPACT OF INADEQUATE VENTILATION AND DISCHARGE SYSTEMS

In addition to analysis of the cause, the investigation also evaluated the role of the ammonia detection, ventilation and discharge systems following the ammonia release. This analysis determined the ventilation system could not have prevented the large concentration of ammonia within the room, and that it may have contributed to the spread of ammonia to other areas of the arena. It was also determined that the deployment and configuration of the emergency discharge system introduced risk while not reducing the amount of ammonia released into the mechanical room.

The investigation found that the configuration and capacity of the ventilation system could not have prevented extremely high levels of ammonia from accumulating within the mechanical room due to the rate of ammonia release. Additionally, the fan belt for the leak/rupture fan was worn and the location of this fan was such that ventilation performance was inefficient; extending the period of time required to reduce the ammonia concentration within the room following the leak.

Location of the fans in a recessed area of the roof also prevented exhausted air from reaching the outside airstream and may have directed exhausted ammonia toward air inlets in the arena building.

This may have contributed to the ammonia concentration of 400 ppm measured in the arena lobby hours after the incident. It is also possible that ammonia detected in the lobby may have escaped the machine room through a gap beneath the door to the vestibule and an unsealed door between the vestibule and the public area of the arena.

Following the incident, first responders opened the emergency discharge valve which released ammonia into the atmosphere, contributing to the declaration of a local state of emergency and the evacuation of 95 residents from 55 homes near the arena. Examination of the system configuration and condition determined that the release of ammonia via the emergency discharge valve did not reduce the risk of ammonia exposure within the mechanical room. Further examination of pipe routing and system requirements concluded that the arena's emergency discharge system introduced additional exposure risk.

Recommendations

Based on the findings of the investigation, Technical Safety BC made 18 recommendations to improve management of safety risks related to refrigeration systems. These recommendations aimed at arena owners, maintenance contractors, training providers, local governments, and the Canadian Standards Association appear at the conclusion of the report and are published on Technical Safety BC's website at technicalandsafetybc.ca.

SCOPE OF INVESTIGATION

The discussion and conclusions in this report are based upon the evidence presented and available at the time of Technical Safety BC's investigation, conducted between October 2017 and June 2018. The investigation sought to understand both causal and contributing factors that led to the ammonia release. Factors subject to the Act and Regulation that contributed to the impact to the area and community following the release were also investigated. This scope is graphically represented in the diagram below (Figure 2) which depicts both pre-incident and post-incident variables.

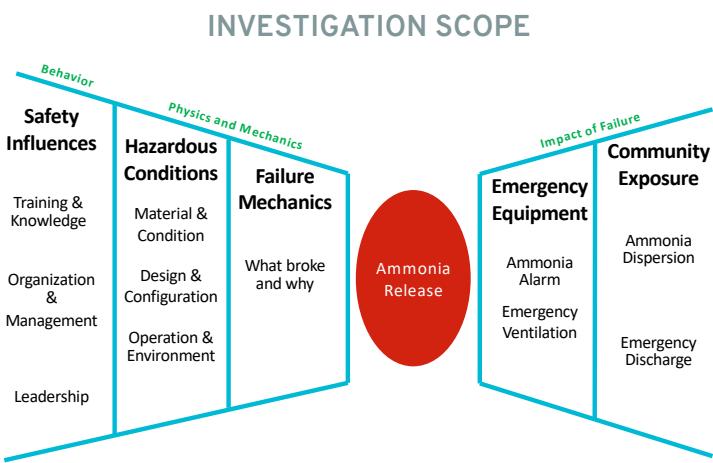


Figure 2: Technical Safety BC's investigation scope depicting the relationship of factors to the incident (ammonia release). Pre-incident contributing factors are represented to the left of the incident, and post-incident factors to the right.

The purpose of Technical Safety BC's investigation was to understand the causes and contributing factors that led to the incident and its impact. Technical Safety BC's investigation aims to inform prevention to reduce the risk of an incident of this nature recurring in the future. Sections I and II of this report provide analysis of the technical and operational conditions that led to the incident. Section III addresses additional findings of the investigation related to the function of incident mitigation systems, specifically the ventilation system and the emergency discharge system.

The scope of activity undertaken during the investigation included:

- documentation of the scene;
- examination of log books, manuals and procedures;
- integrity inspections, tests and analyses of refrigeration system equipment;
- operational tests of the ammonia detection and ventilation systems;
- laboratory analyses of the curling brine chiller, brine system pipe couplings and valves;
- analysis and simulation of ammonia release and dispersion;
- interviews of current and past City of Fernie employees and maintenance contractors;
- examination of email correspondence relating to the Fernie Memorial Arena;
- examination of budget and financial management between 2010 and the incident date;
- examination of strategic planning materials related to the arena and asset management;
- examination of arena work, inspections and service orders between 2010 and the incident date;
- evaluation of the organizational structure, turnover and management incentives at the City of Fernie;
- examination of industry asset management planning materials;
- evaluation of qualifications and training materials for refrigeration industry workers; and
- benchmarking of maintenance practices and industry behaviours at other arenas and service providers.

INVESTIGATION FINDINGS I

FAILURE OF REFRIGERATION SYSTEM EQUIPMENT

● SUMMARY

Ammonia was detected to have leaked into the curling brine system during the 2016/2017 operating season at the Fernie Memorial Arena. Examination of the curling brine chiller after the incident identified the source of the leak as a carbon-steel tube failure within the curling system brine chiller. The failed tube showed evidence of corrosion pitting along the inner tube walls with accelerated pitting on an electric resistance weld line due to weld line fusion defects. A corrosion penetration occurred at a weld location resulting in a hole measuring approximately 2.2 mm x 0.2 mm with potential adjacent smaller holes along the same weld line.

The potential for corrosion in this type of system results from the chemical reactions between the calcium chloride brine solution and the carbon steel welded tubes. Brine systems of this type are also subject to periodic air ingress that can promote corrosion. Removal of this trapped air from the system is part of regular operation and maintenance. Evidence indicates that a corrosion inhibitor (brinehib) was being added periodically to the brine solution to slow the corrosion process within the system.

Corrosion penetration is one type of wear-out failure risk that can increase with the length of service or age of equipment and become accelerated at some defect areas. Vessels in similar service conditions are generally considered to have a useful life of 20-25 years, although there are many factors that influence how long a vessel might remain serviceable. The curling chiller was manufactured 31 years prior to its failure in 2017. The investigation did not discover documentation indicating the exact date the chiller was put into active service at the facility.

Detection of a curling chiller ammonia leak during the 2016/17 operating season first occurred during seasonal shutdown in April/May of 2017. The curling system remained shut down through the summer months and was re-started on October 16, 2017. Hours after starting the curling system, ammonia that leaked into the brine began to accumulate into the mechanical room through the brine expansion tank. At 3:53 a.m. on October 17, 2017, an ammonia alarm was triggered within the mechanical room when a concentration

of 100 ppm was detected. Brine had also leaked into the ammonia system and was detected in the compressor oil.

In response to the ammonia leak, the brine expansion tank and curling chiller were isolated. This isolation impeded brine expansion while isolating liquid ammonia within the leaking chiller. The brine system was shut down and valves were closed at the pump, inhibiting absorption of the leaking ammonia throughout the entire brine system volume. In response to the brine leaking into the ammonia system, a service call was arranged for a mechanic to perform an oil change that morning.

As ammonia continued to leak into the brine, the brine nearest the leak likely reached ammonia saturation concentrations. The likely effects within the brine system near and within the chiller were:

- an ammonia saturated volume of brine;
- a temperature increase;
- a pressure rise within the brine system and chiller; and
- a displaced volume of brine from ammonia being added to the saturated solution.

A brine system pipe segment near the curling chiller was joined at two locations by pipe couplings. These joints were not supported to resist movement from pipe loading due to pressure or mechanical forces. The rising pressure within the brine system eventually exceeded the strength of the joint and one of the coupling joints separated.

Once the coupling separated, the brine system piping suddenly depressurized and the ammonia within the solution and piping rapidly expanded. The contents of the pipe were propelled out by the rapidly expanding ammonia. The released ammonia quickly expanded within the room, reaching estimated concentrations above 20,000 ppm within the mechanical room.

The Fernie Memorial Arena mechanical room scene is documented in photos in Appendix C for reference. An itemized system schematic is provided in Figure 3.

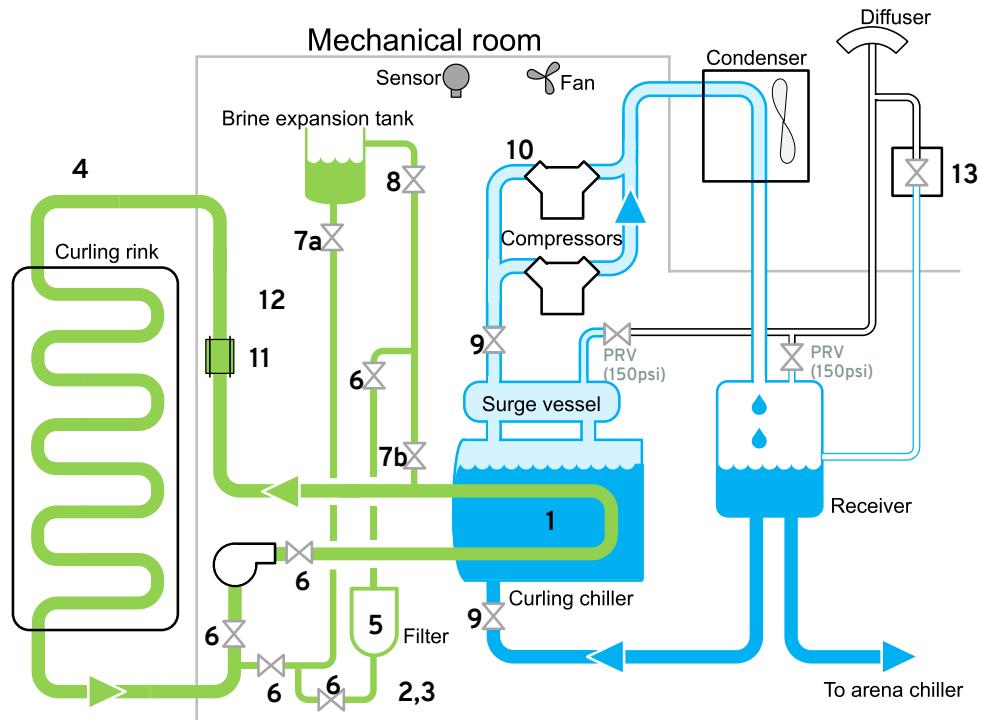


Figure 3: Schematic of the Fernie Memorial Arena curling refrigeration system. Numbers identified correspond to the items and descriptions in the Table 1 below.

Reference Table for Numbered Items in Figure 3 – Fernie Memorial Arena Schematic

#	ITEM DESCRIPTION & FINDING	#	ITEM DESCRIPTION & FINDING
1	Curling Brine Chiller – One 2.2 mm x 0.2 mm hole found in an upper tube along a weld seam.	7a 7b	Valve found in OPEN position Valve found failed in OPEN position
2	Brine analysis results – prior to incident: (sample locations indicated as item 2) 0 ppm ammonia – Jan 2016 3,320 ppm ammonia – May 2017 1,830 ppm ammonia – Aug 2017	8	Valve concluded to be effectively CLOSED. A very small opening may have facilitated some leakage, while pressure relief was impeded.
3	Brine analysis results – post-incident: (sample locations indicated as item 3) 113,400 ppm ammonia measured on Oct 20 2017	9	Ammonia system valves found CLOSED, isolating an estimated 90 lb. ammonia in chiller
4	Brine analysis results – post-incident: (sample locations indicated as item 4) 5,395 ppm ammonia measured on Oct 23 2017	10	Compressors contaminated – salt deposits found indicate brine leaking from chiller
5	Brine filter changed April 13, 2017 – log book notes strong smell of ammonia. Filter valve found plugged and filter element clean	11	Separated brine system coupling. Pipe segment not supported for pressure loading
6	Brine system valves found CLOSED	12	Brine spray in mechanical room
		13	Emergency discharge valve (firebox) - OPEN

Table 1: Items and descriptions as referenced from Figure 3 – Curling Refrigeration System Schematic. Item numbers (#) correspond to the components and system locations in the schematic, Figure 3.

● FINDINGS RELATED TO THE CURLING BRINE CHILLER

Multiple potential sources of an ammonia leak were examined and tested. The curling brine chiller was determined to be the only source of ammonia that could have leaked into the room. This conclusion was determined based on several factors:

- Leak tests and visual inspections of all ammonia system piping and equipment did not reveal any leaks other than within the curling system chiller.
- Brine analysis reports indicated the curling system chiller was leaking prior to the incident.
- Following ventilation of the room, the only source of ammonia detected to be entering the room was measured at the separated curling brine system coupling.
- Higher ammonia readings were detected at the separated brine system pipe connected to the chiller.
- The arena system brine analysis did not indicate an ammonia leak from the arena chiller.

When the chiller heads were removed in the mechanical room in January 2018, they revealed the following:

- Tubes and tube sheets appeared corroded and contaminated.
- Lower tube contamination was dark and oily in appearance.
- Contamination was soluble in water.
- Ultrasonic measurement detected one leaking tube (row 2, tube 3).
- The identified leaking tube was noticeably less contaminated than other tubes.



Photo 1: Curling chiller opened showing contamination. The leaking upper tube is identified by the white arrow – second row, third tube from the right side of the photo.



Photo 2 (above): outside of failed tube showing hole and corrosion due to brine spray.

Photo 3 (right-upper): close-up of hole from outside surface of tube.

Photo 4 (right-lower): close-up of hole from inside surface of tube showing pitting corrosion and line of smaller pits along weld line (Appendix E).

Destructive testing and laboratory analysis of the chiller was completed and included in Appendix E. A leak check of each tube confirmed only the one identified tube was leaking. The failed tube showed evidence of corrosion pitting along the inner tube walls with selective pitting on an electric resistance weld (ERW) line. The tube ERW weld lines were found to contain fusion defects resulting from the welding process that increased the potential for corrosion in unfused areas (Appendix E). A corrosion penetration occurred on the ERW weld seam resulting with a hole measuring approximately 2.2 mm x 0.2 mm. Adjacent smaller pits along the same ERW weld line were identified that may have penetrated the tube wall.

• FINDINGS RELATED TO THE DETECTION OF AMMONIA IN THE CURLING SYSTEM BRINE

High ammonia levels were detected within the curling system brine solution. It is likely that at the time of the incident, the ammonia concentration within the brine closer to the leak within the chiller was much higher. Following the incident, a sample within the mechanical room close to the chiller detected 113,400 ppm ammonia, while a sample further from the chiller, outside of the mechanical room measured 5,395 ppm ammonia.

As part of the annual shut-down of the facility's refrigeration system, the maintenance contractor took samples and coordinated brine analysis to monitor for a number of items, including the presence of ammonia. Ammonia concentrations measured during this time were as follows:

- January 2016 – No ammonia was detected in the sample.
- April 13, 2017 – during interviews, city employees stated that there was an ammonia smell from the brine. The maintenance log also recorded “a strong smell of ammonia in the curling rink filter” following a filter cleaning task.
- May 2017 - 3,320 ppm ammonia detected in a sample and a recommendation was made by the maintenance contractor to monitor and take another sample.
- August 2017 - 1,830 ppm ammonia detected in a sample. The reduced concentration is likely due to off-gassing throughout the summer months while the brine sat idle in the system. During shutdown periods the liquid ammonia is pumped out of the chiller shell side with minimum vapour remaining.

Results from the May 2017 brine sample analysis with a recommendation by the maintenance contractor to monitor was found within the mechanical room (Appendix C). The brine analyses conducted indicate the curling chiller had begun to leak ammonia into the curling system brine during the 2016/2017 operating season.

● FINDINGS RELATED TO THE VALVE POSITIONS

The valve positions of the ammonia and brine systems were recorded prior to any manipulation for hazardous materials removal. These valve positions, documented in Appendix B and Figure 4, record those positions immediately following the incident. An analysis of the timing for isolation and system shutdown (Investigation Findings II) concludes that these valve positions, with the exception of the closed valves at compressor #1, likely represent how the system was configured after the shutdown at 4:30 a.m. on October 17, 2017.

This configuration isolated an estimated 90 lb. of ammonia within the chiller (Appendix A) and inhibited brine system venting and pressure relief through the expansion tank.



Photo 5: Brine expansion tanks – closed valve positions as found after incident shown in photo insets. Main photo taken after hazardous material removal.

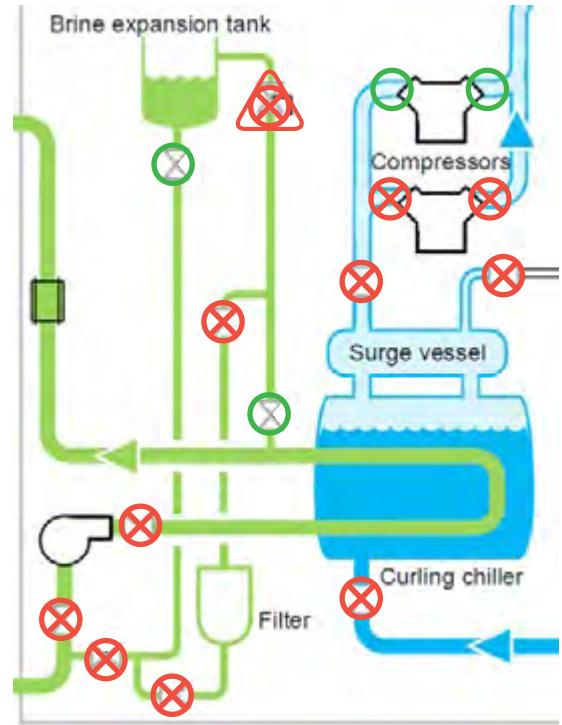


Figure 4: Valve positions found resulted with liquid ammonia contained in the leaking chiller and no pressure relief in the brine system.

CLOSED

**EFFECTIVELY
CLOSED**

OPEN

An inlet valve to the curling system brine expansion tank was found slightly cocked, as shown in the upper inset of Photo 5. The valve handle had been re-installed in a flipped condition allowing for a different orientation and range of motion. Lab analysis (Appendix E) estimated the handle angle at 10 degrees from perpendicular. Radiography and leak testing to determine if the valve was fully closed or permitting free flow (unplugged) was inconclusive. An exemplar valve was configured per the as-found valve and suggests this valve may not have been completely closed. In such an ‘almost closed’ and unplugged configuration, this valve may have facilitated some leakage while impeding pressure relief from brine expansion or displacement. This valve is concluded to be effectively closed but

may have contributed to a small leakage of ammonia or brine as the brine system pressurized.

The log of ammonia alarms recorded by the alarm monitoring company for the Fernie Memorial Arena (Appendix G) indicates a number of ammonia alarms in the morning leading up to the incident. It is reportedly common for ammonia alarms to be triggered while work on a refrigeration system is being conducted and refrigeration mechanics reported it is common for those alarms to be disregarded. These alarms could have been triggered from ammonia escaping at the brine expansion tank, brine system coupling locations or as compressor #1 was being prepared for ammonia purging in anticipation of the upcoming oil change.

● FINDINGS RELATED TO BRINE CONTAMINATION WITHIN THE COMPRESSORS

In addition to the ammonia leaking into the brine system, brine was also leaking into the ammonia system through the leaking chiller tube.

The compressor oil was identified in the maintenance log on October 16, 2017 as being milky. Following the 3:53 a.m. alarm and subsequent system shutdown on October 17, 2017, the maintenance contractor was requested to dispatch a mechanic to get the refrigeration system running for the arena system and to perform

oil changes on the compressors due to the visual appearance and level of the oil.

Oil with a cloudy or milky appearance is identified as an indication of a water/brine contamination. The compressor and cylinder heads were removed post incident and inspected which revealed the presence of salt deposits most likely from brine contamination of the ammonia.



Photo 6: Compressor #2 (#1 similar) showing salt crystal build-up on lower compressor cylinder heads, upper heads were clean.



Photo 7: Build-up of salt crystals from brine around lower compressor cylinder heads of compressors #1 and #2.

○ FINDINGS RELATED TO THE SEPARATED BRINE SYSTEM COUPLING

Rising pressure from the ammonia leak into the isolated brine system exceeded the strength of a coupling joint in the brine system piping located near the curling chiller. The separated joint relieved the pressure, which resulted in rapid release and expansion of the ammonia within the brine system and solution.

As shown in Figure 5, a segment of the brine system piping was connected by two in-line water system couplings. One coupling was oriented vertically while the other horizontally. The pipe segment weight was supported on a wooden block at one location. There was no support for either longitudinal or torsional loading.

The horizontal coupling was found separated as shown in Figure 5 and Photo 8.

As part of the investigation, a test was conducted to evaluate the pressure required to separate a similar pipe coupling. A new exemplar coupling was installed per the manufacturer's specifications onto 4-inch diameter piping similar to that used at the Fernie Memorial Arena. The pipe-coupling joint was pressurized and at 30 pounds per square inch (psi) the coupling began to slip toward separation.

The curling chiller is protected on the shell side (ammonia) by an over-pressure relief device set to relieve at 150 psi. This valve was tested and demonstrated to relieve at the designed pressure. An inspection revealed no evidence of brine deposits within the valve. It is concluded that the overpressure relief device likely did not activate.

It is therefore estimated that the pressure within the brine system reached between 30 psi and 150 psi. The friction from the weight of the pipe and the torsional friction of the vertical coupling would have added to the force needed to separate the coupling beyond that associated with the 30 psi coupling separation pressure.

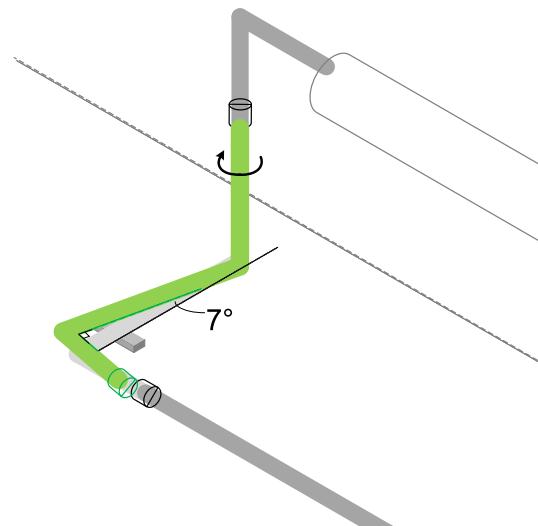


Figure 5: Piping segment installed with in-line water system couplings.



Photo 8: Separated brine system coupling.



Photo 9: View looking down on pipe segment between vertical coupling and horizontal coupling. Angle of rotation estimated at approximately 7 degrees.

● FINDINGS RELATED TO AMMONIA-BRINE SPRAY INTO MECHANICAL ROOM

Once the brine system coupling separated and relieved the internal pressure, the ammonia in solution and any ammonia in the brine pipe quickly expanded, projecting the contents of the brine pipe outward from the pipe opening. The ammonia quickly vaporized and expanded to fill the mechanical room reaching estimated concentrations exceeding 20,000 ppm.

Evidence of brine chiller and pipe contents projecting from the separated brine system coupling was observed immediately following the incident as shown in Photo 10 and Photo 11 below.



Photo 10: Separated coupling and projected brine system contents. Photo taken on October 18, 2017.



Photo 11: Projected contents of the brine piping from the separated coupling.

Exposed copper pipe and locks within the mechanical room were observed to be corroded (blue) indicating exposure to ammonia.

Residue patterns were observed on the mechanical room walls and around the maintenance log books that are consistent with having originated from the separated coupling as shown in Figure 5.

Samples from the residue on the walls were taken and analyzed. The results are contained in Appendix I and identified the likely presence of calcium chloride, consistent with brine having originated from the chiller/brine system piping.



Photo 12: Lock-out board showing corroded (blue) copper consistent with ammonia exposure.



Figure 6: Photos of residue locations on the mechanical room wall. Pattern location is consistent with originating from the separated brine coupling. Samples of the residue tested identified a likely presence of calcium chloride consistent with brine.

INVESTIGATION FINDINGS II OPERATIONAL DECISIONS THAT CONTRIBUTED TO THE INCIDENT

● SUMMARY

Technical Safety BC's investigation sought to gain insight into the operational context in which the incident occurred. Correspondence and administration records were examined from the City of Fernie and maintenance contractors and interviews were conducted with key personnel relating to the management of the equipment that failed. The evidence gathered indicates that there were five discernable key decisions made between 2010 and October 17, 2017 that contributed to the incident. While the impact of these decisions may be evident in hindsight, Technical Safety BC did not discover evidence that foresight of the eventual outcome was apparent at the time they were made.

The timeline below shows the chronological occurrence of this decision chain, starting with documented recommendations in 2010 to replace the aging curling chiller.

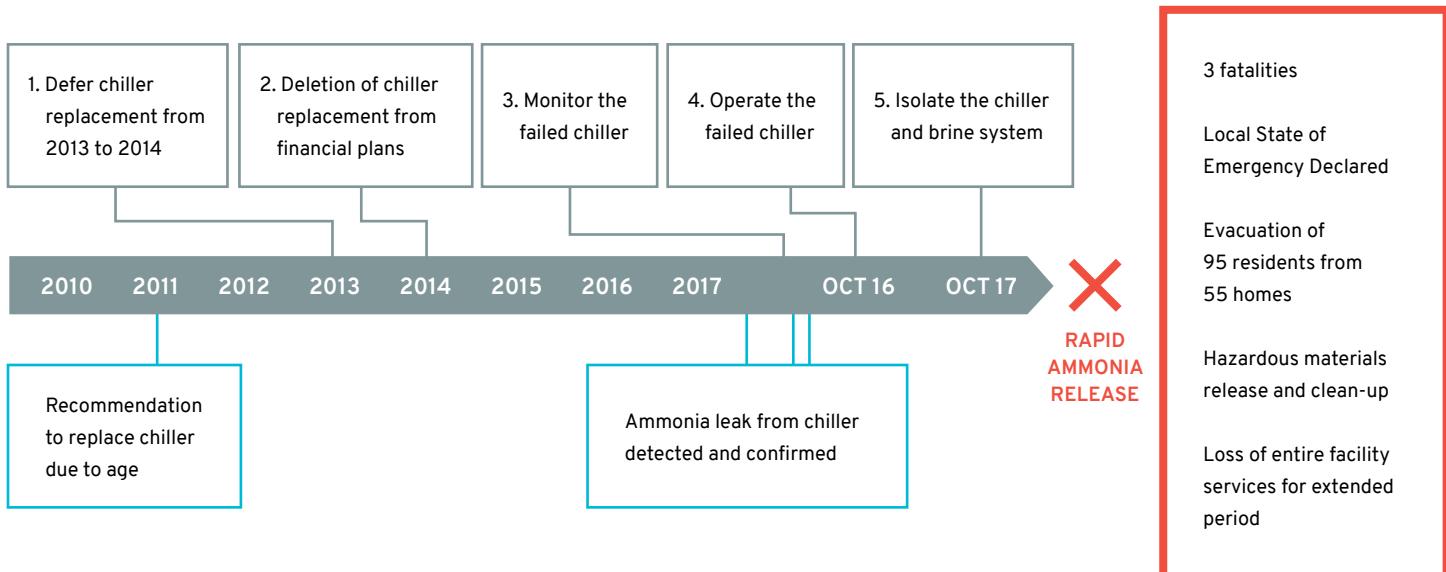


Figure 7: Timeline of key decisions that contributed to the eventual rapid release of ammonia into the mechanical room on October 17, 2017.

The decision to isolate the curling chiller and brine system is directly connected to the system configuration and equipment failure, as described in the previous section of this report. This decision was made in response to a situation that resulted from preceding decision outcomes affecting the refrigeration system and curling chiller. These decisions contributed to the situation that developed on October 17, 2017, where a leaking chiller and system configuration resulted in a rapid ammonia release.

Evidence identified a number of potential influences for these decisions. These influences include organizational and departmental priorities, employee turnover, organizational design, ineffective communications, and a lack of hazard awareness associated with leaking chillers and aging equipment.

○ FINDINGS RELATED TO THE DEFERRAL OF THE CHILLER REPLACEMENT

In October of 2010 and January of 2011, the City of Fernie's maintenance contractor made a series of recommendations (Appendix L) to address non-compliances with technical safety codes, the aging condenser and the aging curling club chiller, as well as energy efficiency improvements. The curling club chiller, manufactured in 1986, was proposed by the maintenance contractor at that time as having reached or surpassed its life expectancy of 20 to 25 years.

The City of Fernie scheduled spending to address the code non-compliances (plant overhaul) in 2011, the condenser replacement in 2012 and the curling club chiller replacement in 2013.

In 2013, the replacement of the chiller was deferred to 2014 as shown in the 2013-2017 Five-Year Financial Plan deliberation (Appendix N).

Evidence identifies that the chiller replacement deferral from 2013 to 2014 was likely influenced by other priorities for the refrigeration system.

Documented deliberations on arena capital spending in 2013 show that compressor work/replacement was scheduled earlier than initially planned (2016) and a previously unplanned replacement of the brine tanks became scheduled into 2013. At this time, the planned 2013 chiller replacement appears in public consultation documents as deferred to 2014. Given that the total allocated funds for each of these activities was similar, it is likely that this rescheduling of expenses replaced one activity with the others in 2013.

Recommendations		Planned Expenses / Activities		
2010 / 2011		2011	2012	2013
1	address Code non-compliances	plant overhaul (code non-compliances)	replace condenser	replace curling chiller
2	replace condenser (aging/failing)			
3	replace curling chiller (aging)			

Table 2: 2010/2011 Recommendations made by the maintenance contractor were translated into planned expenses for 2011-2013.

○ FINDINGS RELATED TO THE DELETION OF THE CHILLER REPLACEMENT FROM CAPITAL SPENDING PLANS

In 2014, the reference to the curling chiller replacement disappeared from five-year financial/capital spending plans and subsequent years' capital spending plans. The chiller replacement was no longer a budgeted activity, however it remained as an item in various management documents following 2014, including the City's 2014-2018 Corporate Strategic Plan, 2016 Business Plan, and management capital planning worksheet for 2017. In addition, five quotes were requested by the City for chiller replacement between January 2015 and August 2017.

Evidence identifies that the deletion of the curling chiller replacement from approved financial plans may have been influenced by the a number of variables, including: 1) employee turn-over; 2) the organization's design of the leisure services department; 3) the introduction of a Facilities Master Plan; and 4) the refrigeration system maintenance plan.

Employee Turnover

The original recommendation to replace the chiller was made in 2010 to the director of leisure services at that time. By 2014, when organizational commitment for the scheduled replacement was required, those in the director and the chief administrative officer positions when the recommendation was made in 2010 had both left the organization (see Appendix O). Both the director and the chief administrative officer in those roles in 2013 and 2014 stated that they were not explicitly aware of the recommendation made in 2010 by the maintenance contractor to the director.

Employee interviews identified that the chief administrator's involvement is key to securing council approval for the director's capital spending proposals within the five-year financial plans. Current and past directors stated that securing resource commitment required a strong business rationale for the expenditure to be presented to Council and that resources were secured within the active year of the plan.

Employee turnover created a situation where the director that originally scheduled the future chiller replacement and the chief administrative officer who supported its inclusion into the five-year financial plan were no longer employed in the year that organizational commitment to the activity was needing to be secured.

Organizational design of the Leisure Services Department

According to the organizational chart for the City of Fernie and the job description for the director of leisure services (appendices R and S, respectively), the director was responsible for a wide array of duties which included: leisure services delivery and planning; facility equipment and infrastructure management and planning; and human resources management and planning for the Leisure Services Department.

A draft report prepared for the City of Fernie titled Asset Management Investment Plan 2018 Final Report identifies that 80% of the building infrastructure is represented by leisure services, which includes 17 buildings with a replacement value in excess of \$60,000,000. The report identifies that 39% of the building assets are in poor condition, based on their age.

Current and previous colleagues of the deceased director and past incumbents of the role expressed the role was stressful, with many aging infrastructure challenges and a substantial number of projects.

Interviews confirmed the structure of the organizational chart, which shows all employees in the department (24 minimum) reporting directly to the director and includes no manager or supervisor supporting the facility management work of the director.

Within the context of the director's workload and scope of responsibility for aging infrastructure, the chiller replacement recommendation was described as being unremarkable, given the many similar types of change recommendations for the position to assess and manage. The broad scope of responsibility within the role, combined with the competing demands of multiple aging infrastructure priorities, may have contributed to the chiller replacement being deleted from approved financial plans in 2014 and future committed expenditures.

Introduction of the Facilities Master Plan

In 2013, the City of Fernie contracted the production of a Facilities Master Plan that was completed in 2014. The document included assessments of the City's facilities, capital cost and life-cycle cost analysis, preventative maintenance plans and recommendations for future spending and priorities for the facilities and equipment.

The Facilities Master Plan was identified as being produced in response to a need to assess and anticipate the needs associated with managing aging infrastructure. The plan acknowledges immediate safety-related observations however it does not address changing safety risk as infrastructure ages. Future risks are expressed as a risk of operational service loss or financial expense. This focus of risk awareness toward service or financial disruption was found consistent with industry guidance documents available throughout the decision period.

Assessment of equipment condition within the Facilities Master Plan was limited to basic visual inspections. The assessment page included for the curling brine system chiller rated its condition as "Good" and "Meets all present requirements. No deficiencies", even though the vessel was not visible under the insulation and had been recommended for replacement due to age three years prior to this assessment.

At the time of the incident, the City of Fernie was drafting a final report titled Asset Management Investment Plan 2018 which was provided to the investigation for review. This report identifies that a *failure to plan would put the community at risk of service disruptions, emergency repairs and the need for sudden and significant tax and user*

fee increases. Safety risk is not identified as a considered factor or component of the analysis.

By failing to include safety risk management as an objective in the management of aging infrastructure, important safety and environmental impacts may not have been considered or fully assessed by qualified professionals.

A financial planning and spending analysis (Appendix M) shows that prior to the introduction of the Facilities Master Plan, capital planning and spending for the arena focused on replacement of aging refrigeration system components and larger maintenance costs as recommended by the refrigeration maintenance contractors. In 2014 and years following the Facilities Master Plan, planning and spending on the arena changed to general building upgrades as recommended by the Facilities Master Plan, as well as energy efficiency improvements.

It is possible that the recommendations of the Facilities Master Plan influenced a change in capital spending priorities on the arena, with an increased focus on building and energy improvements.

CURLING CHILLER REPLACEMENT PLANNING

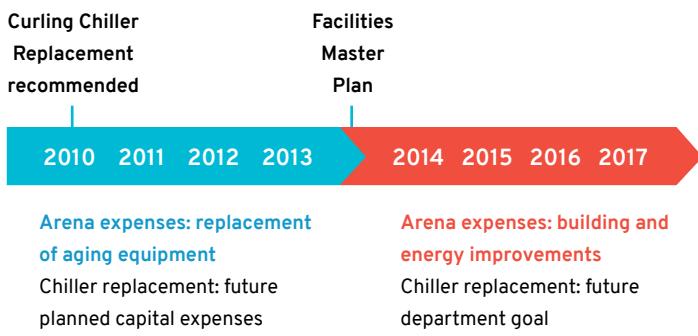


Figure 8: Fernie Memorial Arena expense type and curling chiller planning following the recommendation in 2010.

Refrigeration system maintenance plan

The maintenance plan for the refrigeration system and mechanical room at the Fernie Memorial Arena consisted of a listing of daily, weekly, monthly and annual tasks and associated procedures; a maintenance log book; and a limited service contract with

a maintenance contractor for seasonal start-up, mid-season assessment and shutdown of the refrigeration system, including brine testing for both the arena and curling brine systems.

This type of plan is often referred to as a preventative maintenance plan due to the presence of interval scheduled tasks which are preventative in intention. Technical Safety BC evaluated the City of Fernie's maintenance plan and maintenance contract against a sample of other BC arenas and maintenance practices (see Appendix V). This review found the City of Fernie's plan and contract to be typical of other arenas assessed and consistent with existing training materials for refrigeration operators, refrigeration mechanics and 4th class power engineers.

A robust maintenance program typically involves a variety of strategies as indicated in Table 3 and includes knowledge of wear-out or equipment end-of-life.

Preventative maintenance strategies include an understanding of concepts such as: mean-time-between-failures for repairable items, and mean-time-to-failure for non-repairable items. These estimates determine the inspection, task and replacement intervals in a preventative maintenance program and effectively manage the end-of-life of components and systems by preventing operation into the wear-out phase of their life-cycle.

Strategy	Description
Corrective	Inspections, repairs, replacements carried out following detection of anomalies.
Preventative	Inspections, repairs and replacements are scheduled at pre-determined intervals.
Predictive	Regularly assess condition and repair or replace prior to estimated failure.
Reliability-centered	Analyze failure modes and customize inspections, repairs and replacements based upon desired reliability.

Table 3: General Maintenance Strategies

Corrective maintenance was the most commonly described strategy by contractors and operators, whereby components are operated until they show signs of failure or they fail. Misinterpreting attempts to pre-empt failure or minimize the impact of failure

as being ‘preventative’ or ‘predictive’ can occur, and corrective maintenance is only appropriate where the consequences of failure are understood and accepted.

As part of this investigation, Technical Safety BC conducted a survey of maintenance regimes at other arenas comparable to the Fernie Memorial Arena (Appendix V) and evaluated brine testing results submitted to the investigation and in response to a safety order issued following the incident. A number of chillers were suspected to have ammonia leaks and considered failed. The results of the failed chillers relative to their age are shown plotted as a bathtub curve in Figure 9.

This data indicates that the risk of an arena brine system chiller failure due to wear-out begins to increase after 18 years of service. This timeframe supports the replacement recommendation made by the refrigeration contractor based on an average lifespan of 20-25 years as a reasonable estimate of the mean-time-to-failure for a chiller in this type of service.

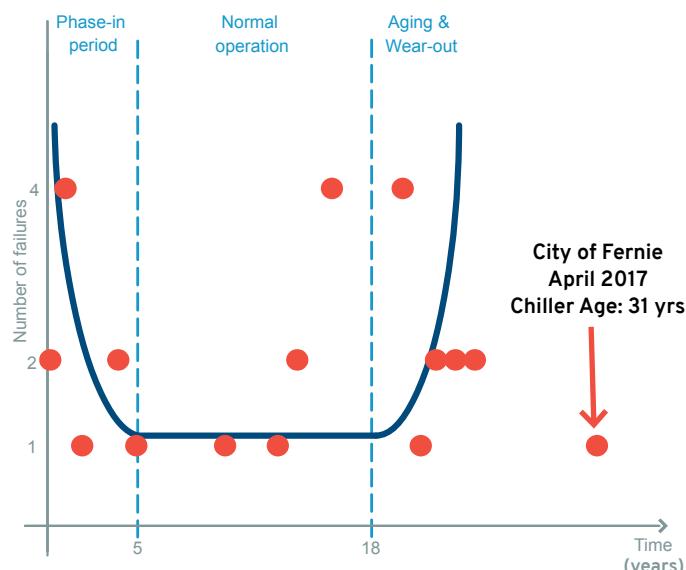


Figure 9: “Bathtub” curve showing arena brine system chiller failures detected via ammonia in the brine.

A review of training material for refrigeration operators, refrigeration mechanics and fourth class power engineers (Appendix U) identified that none of these programs provide a comprehensive overview of maintenance strategies or maintenance program elements beyond recommended periodic tasks.

Current and past arena employees and director(s) of leisure services expressed a dependence upon the refrigeration mechanic

or contractor’s sales representative to identify any maintenance planning items. Interviews with these employees and other industry participants identified that maintenance contractors were asked for advice that is outside of their scope of training and qualification as identified in Appendix U.

The City of Fernie’s maintenance plan did not contain equipment end-of-life strategies necessary for an effective preventative maintenance program that would have supported timely replacement of the curling chiller. Maintenance plans that include equipment end-of-life strategies provide a balance towards the expected organizational challenges that compete with resources for equipment replacement.

The failure to include component end-of-life strategies in the maintenance plan may have contributed to the deletion of the chiller replacement from approved financial plans in 2014.



Figure 10: Balancing the needs of equipment life-cycle management and a complex organizational environment.

● FINDINGS RELATED TO THE DECISION TO MONITOR THE LEAKING CHILLER

Evidence obtained by Technical Safety BC indicates that a decision was made to monitor the leaking curling brine chiller in the summer of 2017. Technical Safety BC's investigation identifies evidence that this decision was likely influenced by a failure to recognize a leaking chiller as hazardous.

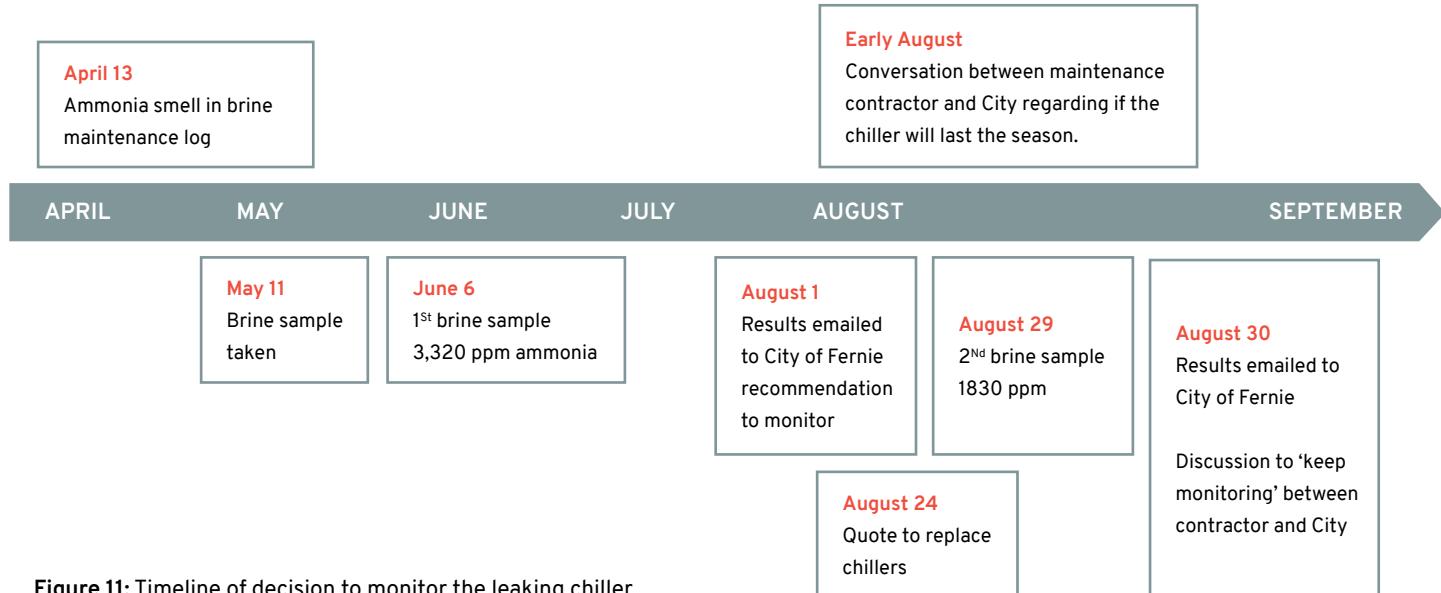


Figure 11: Timeline of decision to monitor the leaking chiller

City of Fernie's awareness of leaking chiller hazards

The decision to monitor and its influence is evidenced through examination of the communications and actions of those persons aware of the leaking chiller between April and September of 2017:

- On April 13, 2017, arena employees stated in interviews having cleaned the brine filters and noted "a strong ammonia smell in the curling rink filter" in the maintenance log.
- On May 11, 2017, as part of the routine seasonal shut down-procedures, the maintenance contractor took a sample of the brine for analysis. It was reported that the refrigeration mechanic that drew the brine sample did not smell an ammonia odour when drawing the sample.
- Laboratory analysis of the brine sample from May 11, 2017 detected an ammonia concentration of 3,320 ppm as indicated in the brine analysis report dated June 6, 2017 (Appendix F).
- On August 1, 2017, the brine analysis report was mailed to the City of Fernie with the instruction from the maintenance contractor, "curling brine shows ammonia – need to monitor – take another sample & advise". A paper (Appendix C, Photo C6-6) found in the mechanical room, near a copy of

the brine analysis report within the mechanical room that states: "Cimco Recommendation - Retest as ammonia may be a false positive as there was no odor at time of sample and this concentration odor would be present".

- An employee of the maintenance contractor stated during an interview that there were many conversations that the chiller had failed, in reference to the results of brine analysis.
- In early August, the maintenance contractor reported a conversation with the City of Fernie in which the City asked how long the chiller would last. The contractor's response was that they did not know (Appendix T).
- On August 24, 2017, the maintenance contractor submitted a quote to replace the curling chiller.
- On August 29, 2017, a second brine sample and analysis (Appendix F) was completed to confirm the presence of ammonia and the results were communicated to the City of Fernie on August 30, 2017 showing a concentration of 1,830 ppm ammonia.
- The maintenance contractor stated in an interview that the dialogue with the City of Fernie following the second brine analysis of August 30, 2017 was to "keep monitoring".

No evidence of further communications was found or reported between the City of Fernie and the maintenance contractor between September and October 16, 2017 relating to the arena and curling refrigeration systems.

Examination of email communications and interviews of key participants indicates no identification or discussion of potential safety hazards or safety risk associated with operating a leaking chiller and no evidence of planning to replace the curling chiller prior to operation.

- Examination of training materials for refrigeration operators, refrigeration mechanics and 4th class power engineers indicates there is no training associated with potential hazards of refrigerant leaks into a secondary coolant.

Evidence examined by Technical Safety BC indicates that the lack of awareness of hazards associated with the leaking chiller at the City of Fernie was consistent with industry awareness. The failure to recognize a leaking chiller as hazardous contributed to the decision to monitor.

Industry awareness of leaking chiller hazards

Technical Safety BC examined industry awareness of hazards associated with leaking chillers to gain an understanding of whether the communications and actions taken at the City of Fernie were consistent with industry practice. Those findings are summarized as follows:

- A web article titled '[Brine Maintenance for Rinks](#)' on the maintenance contractor's website provides interpretation guidance of brine analysis (Appendix W) and identifies the presence of ammonia in the brine as 'a cause for concern', however does not provide discussion of the nature of the concern.
- When asked about the significance of brine analysis, refrigeration operators and mechanics described the activity as managing the brine chemistry rather than understanding from the brine analysis what might be occurring within the system. There was a consistent response that mechanics only pass the results and recommendations of the brine testing laboratory on to the owner.
- An employee of the maintenance contractor stated in an interview that generally they would not recommend operating a leaking chiller but were aware that it happens.
- Technical Safety BC identified instances after the incident where refrigeration contractors recommended or supported operating leaking chillers. These instances included continued leak monitoring through repeat brine testing while operating and continued operation of a leaking chiller until a replacement chiller could be installed or a repair completed.
- The maintenance contractor stated no knowledge of a catastrophic failure of a chiller having ever occurred in the past. These comments were found to be consistent with statements made by other maintenance contractors about the consequences of operating a leaking chiller.

● FINDINGS RELATED TO THE DECISION TO OPERATE THE FAILED CHILLER

Technical Safety BC's investigation concludes that the City of Fernie knew the chiller had failed, yet chose to operate it until a replacement could be arranged. Evidence obtained by Technical Safety BC identifies that this decision was likely influenced by the failure to recognize the leaking chiller as hazardous, an intention to monitor the chiller in operation, and ineffective communication about the condition of the chiller.



Figure 12: Timeline of decision to operate the failed chiller

As discussed in the previous section, there was no evidence to suggest awareness that the leaking chiller presented a hazard and there was industry practice of operating leaking chillers while repairs or replacements are arranged.

Monitor leaking chiller while replacement arrangements made

The last conversation with the maintenance contractor regarding the condition of the leaking chiller prior to operation was reported to include discussion of 'keep monitoring'. The maintenance contractor communicated an understanding that the chiller was not in operation at the time of that discussion and no further dialogue is reported to have occurred or was evident. It is reasonable that the City of Fernie interpreted the monitoring recommendation as referring to monitoring after start-up of the curling chiller.

A capital request dated August 17, 2017 was drafted requesting \$250,000 for replacement of both the curling and arena chillers (Appendix P). This capital request was referenced in the draft minutes of an October 4, 2017 Leisure Services Advisory Board meeting, stating "getting a chiller was mandatory for 2018...the current system is broken". It is noted that interviews pertaining to these draft minutes found that the director was not in attendance and the presentation was made on his behalf. The individual quoted

in the minutes and others in attendance stated they did not recall the statements or having a discussion that the curling chiller was broken.

On October 16, 2017 the City of Fernie refrigeration operator started the curling system, including the brine system chiller, knowing it was leaking, while arrangements were begun to replace the curling chiller in 2018.

Ineffective communication about the condition of the chiller

It is evident from communications regarding the condition of the chiller that knowledge of the leaking condition of the curling chiller was limited to a few individuals (Appendix T). Email and interview evidence with City and maintenance contractor employees indicate that the only persons involved or aware of the decision to monitor and operate the chiller were the director, refrigeration operator, and the maintenance contractor's mechanics and sales account manager.

The maintenance contractor and their employees stated that there is no policy or procedures to manage a response to brine analysis reports where the results are outside of recommended ranges (Appendix T).

Evaluation of the qualification training and provided resumes of the persons in communication about the condition of the chiller concludes that none have exposure to training or qualifications that involve condition/risk assessment beyond troubleshooting, repair and replace activities.

A request was made by the curling club to be able to make ice during the week of October 16, 2017. The curling club representative stated

they were not notified of any risk to the curling season. City of Fernie employees responsible for scheduling events stated they were not notified of any risk to the curling season due to the failed chiller. Members of City of Fernie management stated they were not made aware of the condition of the chiller or a decision to operate.

Technical Safety BC concludes from this evidence that ineffective communication about the condition of the chiller kept knowledge of this condition limited to those without training or qualification to assess the chiller or question a decision to operate in this condition. This ineffective communication may have contributed to the decision to operate the leaking chiller.

● FINDINGS RELATED TO THE DECISION TO ISOLATE THE CHILLER AND BRINE SYSTEM

Evidence obtained by Technical Safety BC indicates that the refrigeration operator placed the system into a shutdown configuration at approximately 4:30 a.m. that contributed to the rapid release later that morning. This configuration consisted of:

1. closed valves to the brine expansion tank;
2. isolating the liquid ammonia within the chiller by closing the chiller suction valve and shutting down the compressors; and
3. shutdown of the brine system circulation pump and closing the circulation valves.

It is possible that these decisions were influenced by the emergency situation of the leak, an operational priority to preserve the arena ice, and no emergency procedures or training relevant to the specific situation.

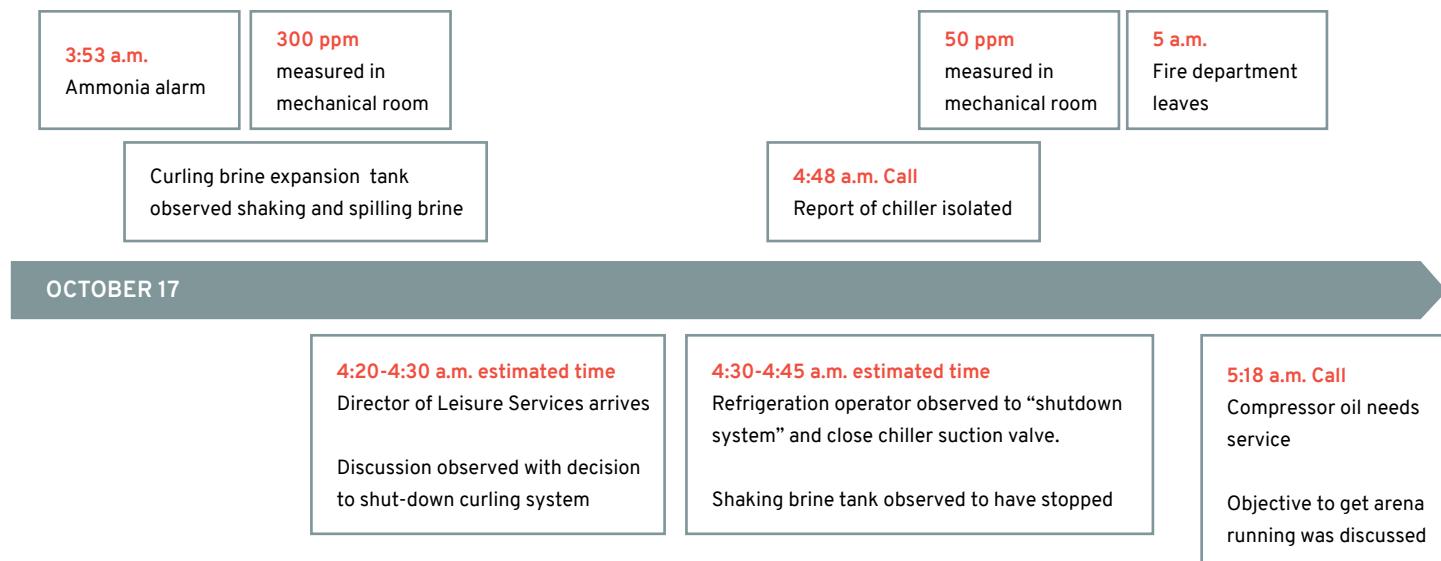


Figure 13: Chiller isolation timeline

Influence of the urgent response on shutdown and configuration

The decision-making context occurred primarily within a one-hour period between 4:00 a.m. and 5:00 a.m. on October 17, 2017 in response to an ammonia alarm at the arena. Understanding the chronology of events within that hour and the few hours that followed illustrates the potential impact that the situation had on that shutdown and isolation decision.

3:53 a.m.

- Ammonia alarm is triggered. Alarm monitoring company dispatches fire department.
- The director and refrigeration operator are notified and respond to the scene

4:00 a.m. estimated

- Firefighters enter arena and assess ammonia levels in mechanical room at 300 ppm.

4:00-4:20 a.m. estimated

- Firefighters accompany refrigeration operator into the mechanical room and report: room was loud upon entry, the refrigeration operator performed methodical visual assessment of mechanical room and manipulated a couple of valves with no effect.
- Firefighters and refrigeration operator exit the arena.

4:20-4:30 a.m. estimated

- Director is met by firefighters upon exit of the arena and conversation occurs between refrigeration operator and director.

4:30-4:45 a.m. estimated

- Firefighters accompany refrigeration operator back into mechanical room and the refrigeration operator turns off equipment and closes multiple valves including the chiller suction valve.
- Firefighters report refrigeration equipment operating noise ceases and curling brine expansion tank stops shaking.
- Ammonia concentration levels in the room decrease. System is described as shutdown.

4:33 a.m.

- Director calls Cimco call-center and reports an ammonia leak and potential *split chiller*. (Appendix T).

4:48 a.m.

- Telephone call between director and maintenance contractor indicating chiller is isolated and system shut down.
- Maintenance contractor requested to send a mechanic to get the arena side back running that day.

5:18 a.m.

- Additional telephone call between director of leisure services and maintenance contractor discussing getting the arena side running, and compressor oil needing servicing.

8:00 a.m.

- Director notifies City of Fernie employee that the curling season is to be cancelled and that they are working to have the arena side open the following day.

From the above it is likely that a decision was made by the director and refrigeration operator at approximately 4:20-4:30 a.m. to shut down the system which was subsequently carried out by the refrigeration operator.

An assessment of the electrical power consumption for the hydro meter associated with the mechanical room equipment (Appendix H) shows that during the 4:00-5:00 a.m. hour considerable less power was consumed, consistent with a refrigeration system shut down midway through the hour. Power consumption analysis also indicates that the refrigeration equipment was not run for any appreciable amount of time after the 4:00-5:00 a.m. time period. This indicates there was likely no attempt to pump the ammonia from the curling chiller per the normal shut-down procedure.

The position of valves immediately following the incident were recorded and confirmed by Technical Safety BC (as shown in Appendix B). Compressor #1 suction and discharge valves were likely closed following the response in preparation for the oil change. Since the system was not likely operated following its shut down, all other valve positions likely represent the system configuration following the shutdown of the refrigeration and brine systems at approximately 4:30-4:45 a.m.

From firefighter reports and valve positions found, it is likely that between 4:00-5:00 a.m. during the emergency response to the ammonia leak, decisions were made to shut down and configure the system. In shutting the system down and responding to the ammonia leak the refrigeration operator isolated the brine expansion tank, isolated the curling chiller without pumping out liquid ammonia and closed the valves for the curling brine circulation.

Influence of arena ice preservation

The ammonia system provided cooling for two brine systems, one for the arena ice floor and one for the curling ice floor. Contamination of or damage to the ammonia system would have an effect on both ice surfaces. The valve positions (Appendix B) for both the curling system and the arena system suggests no intention for an extended shut down of the arena side of the system.

From communication evidence obtained prior to and on October 17, 2017 the refrigeration operator identified suspicion of the curling chiller leaking and having possibly suffered a significant internal failure.

The compressor oil was noted as being *cloudy* and *milky*. This notation, considered in relation to the request for oil servicing, suggests the operator likely suspected curling brine contamination within the ammonia system. It is likely the curling chiller was isolated without pumping out the remaining ammonia in an effort to prevent further brine contamination within the shared ammonia system.

During interviews with City of Fernie employees and residents, it was made readily apparent that the arena is an important and valued facility in the community. Communication and interview evidence indicates that a priority that morning was to return the refrigeration system to operation and preserve the arena ice.

Preservation of the refrigeration system for the arena ice may have contributed to the decision to isolate the curling chiller with liquid ammonia and to arrange for immediate servicing of the compressors by the maintenance contractor.

No emergency procedures or training relevant to the situation

The investigation also considered the broader industry context of emergency management practices for the equipment. Evaluation of training materials for refrigeration operators and refrigeration mechanics found no references to emergency procedures or practices for leaking chillers or shut down configurations. Examination of the City of Fernie's ammonia leak emergency procedures indicates no consideration for system configuration or actions following the initial response to a leak.

Guidelines of this nature have reportedly been omitted due to a wide variety of potential emergency circumstances and the possible consequences of providing the wrong direction. The result is that no guidance or training is provided to assist with situational awareness during such emergencies.

Insufficient equipment emergency procedures and training may have contributed to the decision to isolate the chiller and brine system on the morning of the incident.

INVESTIGATION FINDINGS III

IMPACT OF INADEQUATE VENTILATION AND DISCHARGE SYSTEMS

● SUMMARY

Ammonia odours were reported in the community close to the time of the incident (Appendix D) and firefighters reported measuring 400 ppm of ammonia within the arena lobby during their response. As part of the investigative scope and mandate, Technical Safety BC examined technical systems in place at the Fernie Memorial Arena that are intended to minimize the impact after a release has occurred. In particular, Technical Safety BC's investigation examined the condition of the alarm and ventilation systems to determine if they contributed to the ammonia concentrations experienced within the mechanical room or the community. In addition, the investigation analyzed the configuration and impact of the emergency discharge system deployed in response to the incident.

The Fernie Memorial Arena incorporated an automatic ammonia leak detection, alarm and ventilation system compliant to the leak/rupture ventilation requirements of CSA B52-13. Based on alarm records from the morning of the incident and fire department measurements of ammonia concentrations after the incident, it is very likely the ammonia detection system was functional at the time of the failure.

The investigation found that the configuration and capacity of the ventilation system could not have prevented extremely high levels of ammonia from accumulating within the mechanical room due to the rate of ammonia release. Additionally, the fan belt for the leak/

rupture fan was worn and the location of this fan was such that ventilation performance was inefficient; extending the period of time required to reduce the ammonia concentration within the room following the leak.

Location of the fans in a recessed area of the roof also prevented exhausted air from reaching the outside airstream and may have directed exhausted ammonia toward air inlets on building. This may have contributed to the ammonia concentration of 400 ppm measured in the arena lobby hours after the incident. It is also possible that ammonia detected in the lobby may have escaped the machine room through a gap beneath the door to the vestibule and an unsealed door between the vestibule and the public area of the arena.

Following the incident, first responders opened the emergency discharge valve which released ammonia into the atmosphere, contributing to the declaration of a local state of emergency and the evacuation of 95 residents from 55 homes near the arena. Examination of the system configuration and condition determined that the release of ammonia via the emergency discharge valve did not reduce the risk of ammonia exposure within the mechanical room. Further examination of pipe routing and system requirements concluded that the arena's emergency discharge system introduced additional exposure risk.

○ FINDINGS RELATED TO THE DETECTION AND ALARM SYSTEM

The City of Fernie's ammonia detection system settings are documented in their plant operating procedures as shown in Figure 14.

These settings and the installed system were found to comply with the requirements of the CSA B52-13 Mechanical Refrigeration Code. An inspection and test of the system was conducted simulating ammonia sensor signals and found that the system alarm and response was consistent with the City's required settings.

The ammonia system produced an alarm and response at 3:53 a.m. on October 17, 2017 that was consistent with the measured concentration of ammonia during the fire department response. At 7:33am, the refrigeration operator advised the alarm monitoring company to not dispatch first responders for ammonia alarms until 4:00pm as they were working on the system (Appendix G). This type of instruction is reported by refrigeration mechanics to be common practice when alarms are anticipated and considered nuisances.

Throughout the morning and leading up to the equipment failure the system produced numerous alarm and restore messages that were not dispatched in accordance with the instructions provided. The ammonia detection and alarm system was likely functional at the time of the rapid release of ammonia estimated to have occurred between 9:15 a.m. and 9:38 a.m.

Ammonia Detector Alarm Settings – Plant Vestibule		
Operators are required to read the Ammonia alarm to determine the concentrated ammonia level in the plant room before entry.		
Ammonia concentration (parts per million)	Alarm	Location
0 - 34 ppm	No alarm	Ammonia Detector Plant vestibule
35 ppm	Visual alarm – flashing amber light	Plant room, Arena lobby, Arena ice surface (south wall), & curling ice surface
100 ppm	Fire Alarm Visual alarm – strobe light and Audio alarm	Throughout facility Plant room
NOTE: Wear the proper respiratory protection before entry to the Plant Room. Follow the "Entering the Refrigeration Compressor Room" procedure.		

Figure 14: Fernie Memorial Arena ammonia detection system settings

○ FINDINGS RELATED TO THE VENTILATION SYSTEM

The ventilation system requirements of CSA B52-13 (6.2.5.5) (Appendix X) provide for a minimum volume flow per area of machinery room and a minimum volume flow per amount of refrigerant in the system for leakage or rupture scenarios. It is typical that these two requirements are met by incorporating two fans, with the larger leak/rupture fan being activated by the ammonia detection system.

Paragraph 6.2.5.3 of CSA B52-13 provides a general requirement for location of ventilation within the mechanical room to be at an “elevation where refrigerant from a leak is most likely to concentrate”. This same paragraph provides a general requirement for discharging of ventilation air – “the air shall be discharged to the outdoors in a manner that does not cause inconvenience or danger”.

The ventilation rate was measured and compared to the equipment's capacity and the requirement for the mechanical room at the Fernie Memorial Arena. The results are contained in Table 4 below:

VENTILATION SCENARIO	B52 CODE REQUIREMENT	INSTALLED FAN CAPACITY	ACTUAL MEASURED
Minimum flow rate	375 cfm	800 cfm	1062 cfm
Leak/Rupture Scenario flow rate	3500 cfm	4000 cfm	2619 cfm
Time for 1 room air exchange (volume 7500 cubic feet)	2.14 minutes	1.88 minutes	2.88 minutes

Table 4: Comparison of the ventilation flow requirements, installed capacity and the actual performance.

The fan belt on the large fan was discovered to be cracked and in poor condition as shown in Photo 13. When operating, the fan belt was observed to be slipping, resulting in a reduced average fan speed. The reduced ventilation system capacity was measured as being 75% of that required during a leak/ rupture scenario.

To observe the performance of the ventilation system, a smoke test was conducted. The portion of the room between the air inlet and the ventilation fans remained clear while smoke accumulated on the southwest side of the room as shown in Figure 15. Smoke continued to accumulate toward the side of the room where the vestibule door was located until the smoke candle was exhausted.

The smoke was observed to exit the room ventilation fans and become trapped in a low-point in the roof structure between the elevated arena and curling rink roofs. As smoke accumulated in this low-point, it moved toward the roof edge of the building rather than up and into the outside airstream. Smoke was observed to be ventilated mostly from the small fan. Smoke was observed to move toward an air louver on the arena structure.

Inspection of the vestibule doors identified a gap under the door between the mechanical room and vestibule. The door between the vestibule and the arena public space did not incorporate a seal at the bottom. The gaps and sealing under the vestibule doors provided a possible leakage path for ammonia from the mechanical room into the arena lobby inconsistent with the code definition for tight fitting doors. Photos of the vestibule doors are included in Appendix C.



Photo 13 (above): Leak/Rupture Fan Motor, Pulley and Damaged Belt.

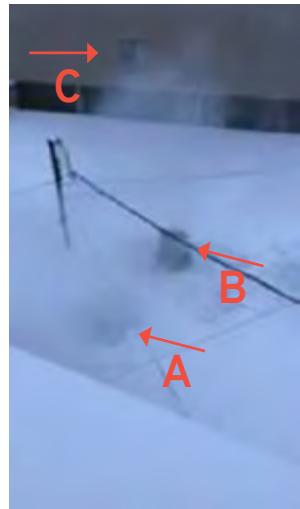


Photo 15 (above): Smoke test showing small fan (A) and large fan (B). Vented smoke shown moving toward air inlet on arena wall (C).



Photo 14 (above): Smoke test showing roof above mechanical room. Smoke became trapped (1) in depression between curling and arena roofs and was observed moving toward the roof edge rather than up into outside airstream (2). The air inlet for the furnace room for the building is identified (3).

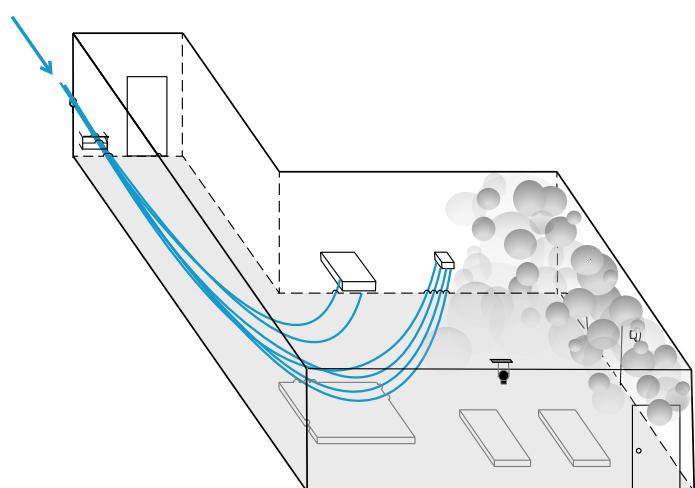


Figure 15 (left): Ventilation airflow through the mechanical room and smoke accumulation along SW wall. The effect of the additional large fan was to move more clean air.

An additional simulation was developed to estimate the ammonia concentration within the mechanical room (Appendix A). The simulation incorporates the estimated ammonia release rate into the mechanical room and the ventilation capacities of the mechanical room. In all simulated cases, the room concentration rapidly reached concentrations exceeding 20,000 ppm ammonia and required several minutes to reduce the levels to below 5000 ppm.

It is possible that the concentration of ammonia reached levels above 20,000 ppm of ammonia and that concentrations above 5,000 ppm remained for several minutes. It is likely that the northeast side of the mechanical room near the vestibule door and maintenance log books remained at elevated concentrations for a much longer period, as a result of ineffective ventilation air flow as demonstrated during the smoke test.

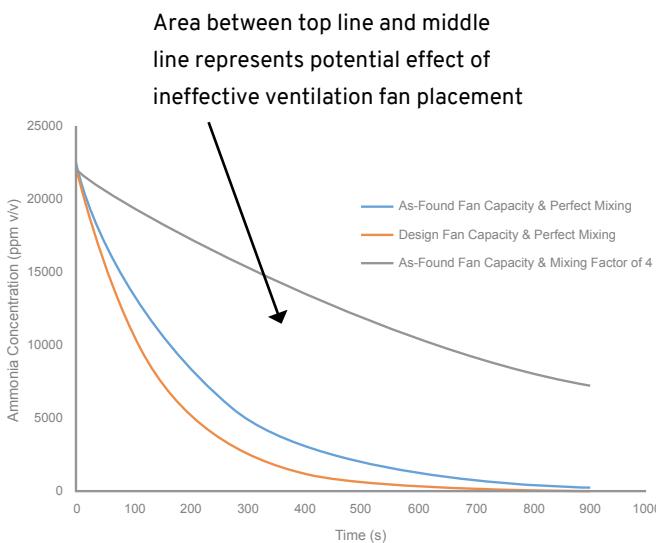


Figure 16 (above): From Appendix A. Simulation result estimating concentration of ammonia within the mechanical room during incident. The top line estimates imperfect mixing of ammonia and room air similar to that observed in the mechanical room, middle line estimates using the required ventilation capacity with perfect mixing and lower line indicates the measured ventilation capacity with perfect mixing.

Leak/Rupture Ventilation Requirements – CSA B52-13 Mechanical Refrigeration Code

The ammonia detection and mechanical ventilation system at the Fernie Memorial Arena was installed to meet CSA B52-13 requirements “to exhaust a potential accumulation of refrigerant due to leaks or a rupture of the system.” Examination of the applicable B52-13 Mechanical Refrigeration Code rules for the alarm, ventilation system and mechanical room suggests the design is intended to:

1. Notify operators of a leak within the mechanical room and the concentration prior to entering;
2. Limit leaking refrigerant from migrating into the occupied building space; and
3. Exhaust accumulated refrigerant safely outdoors where it cannot re-enter the building or harm people.

CSA B52-13 requires mechanical room and vestibule doors to be *tight fitting* which is defined as sealed to prevent the free flow of refrigerant from one space to another.

The CSA B52-13 Mechanical Refrigeration Code identifies a formula and calculation to determine the required ventilation for leak/rupture accumulated refrigerant. This formula determines an air flow rate based upon the amount of refrigerant in a system rather than considering a rate of release/expansion resulting from a leak or rupture.

A 2005 [technical paper](#)² published by the [International Institute of Ammonia Refrigeration](#) (IIAR) concluded that the basis for the formula is not clear but appears to be a best fit curve of ventilation tables derived from a 1927 New York City Code. There is no clear relationship between the leak/rupture ventilation formula and a functional objective for leakage or rupture scenarios.

While the fan belt condition did not produce a leak/rupture flow rate required by the code, its location and incorporation into the room ventilation rendered the fan ineffective at improving the ventilation of the space. Consideration of airflow and a ventilation objective for leakage scenarios is not clearly defined in the code.

² Machinery Room Ventilation for Industrial Refrigeration Systems: A Rational Engineering Analysis. Rex Brown, P.E.

● FINDINGS RELATED TO THE EMERGENCY DISCHARGE SYSTEM

The Fernie Memorial Arena, like many arenas in BC, incorporated an emergency discharge system as described in Annex B of the Mechanical Refrigeration Code CSA B52-13 (see Appendix Y) for the stated intention of providing a means for “safely and rapidly discharging refrigerants into the atmosphere during a fire or other emergency”.

In accordance with Annex B, a discharge line is run directly from the ammonia system to a manually operated valve located outside of the mechanical room in a red, glass fronted box, at least 7 feet above ground. The valve is to be operated by a fire fighter or refrigeration operator and an emergency stop button is to be located next to the valve that removes power to refrigeration equipment in the mechanical room.

Refrigeration Operator training materials associated with this emergency discharge system identify scenarios where discharge valve use might be warranted, such as: fire within the mechanical room; risk of rupture to ammonia piping or components; human entrapment within the mechanical room in the event of a leak or risk of leak. Guidance statements are provided in some industry training manuals to check wind direction to ensure that the release

of ammonia does not present a greater hazard than what is trying to be avoided.

The opening of the emergency discharge valve immediately releases the pressurized ammonia vapour or gas. Evaporation cools the remaining liquid, resulting in a slow and steady release of this remaining liquid refrigerant. The remaining refrigerant will discharge at the rate that heat enters the system inside the room.

The investigation determined that the leak of refrigerant into the room originated solely from the curling brine chiller. This curling brine chiller was found to be isolated from the ammonia system. Inspections and leak testing of the ammonia system determined its pressure retaining integrity had remained intact.

During the initial response to the incident, fire department first responders were instructed by a previous arena refrigeration operator to open the emergency discharge valve and activate the emergency stop button. The valve was opened at approximately 1:50 p.m. on October 17 and was evaluated to have initially released approximately 55 lb. of ammonia into the atmosphere.



Photos 16 (left) and 17 (right): Opened Emergency Discharge Valve and Actuated Emergency Stop Button.

Observations of frost lines on equipment suggest that liquid ammonia remained in the system and continued to evaporate through the opened discharge line for over 24 hours following the opening of the discharge valve. It is estimated that approximately 632 lb. of ammonia evaporated into the atmosphere via the discharge system following the initial release of pressurized vapour from the system (Appendix A).

Frost line observations of the curling brine chiller equipment suggest that liquid ammonia may have remained in the chiller and continued to evaporate into the mechanical room for days following the incident. Due to its isolation, the liquid ammonia in the chiller could not evaporate via the discharge system.

The properties of refrigerants like ammonia render this type of relief device ineffective at providing a means for rapidly discharging the refrigerant in the event of an emergency. Refrigerant remaining within the system following the opening of a discharge valve can introduce risk and complicate subsequent assessments during the emergency response.

At the point that pressurized ammonia vapour was released from the system via the discharge valve, the configuration and state of the system within the mechanical room remained unknown. Managing this unknown condition was a significant component of the risk assessment efforts in the days following the incident.

Training materials suggest that before opening the discharge valve, responders assess the risks vs benefits in light of variables such as wind direction and speed, surrounding population and buildings, and amount of refrigerant to be discharged. In order to make such a complex assessment of whether the risk of release is greater than the risk of allowing ammonia to remain contained in the mechanical room first responders would require knowledge of the configuration and condition of the system within the room. It is unlikely that many responding to an emergency could complete such a risk-benefit assessment during emergency response conditions and timing required for a decision.

• FINDINGS RELATED TO THE DISCHARGE SYSTEM PIPING ROUTING

The ammonia discharge system piping was traced during the investigation, revealing a small diameter ammonia emergency discharge pipe routed through the figure skating storage room (see Figure 17 below). This pipe was located near the ceiling and was routed approximately 14 feet in length through the room. The pipe was supported at only one location, mid-span, by a thin wire wrapped around the pipe and fastened to the ceiling structure above. The ammonia pipe was found with a costume hanging on it and was suspected to have been used as a hanging rod. This pipe had a direct connection to the liquid ammonia system and was charged with ammonia gas at all times.

This pipe could have been mistaken for red fire suppression water piping. If this pipe had broken or been cut at any point, the contents of the liquid ammonia receiver and system would have leaked into the storage room. The emergency discharge system piping presented a risk of ammonia exposure due to pipe routing within the figure skating storage room.

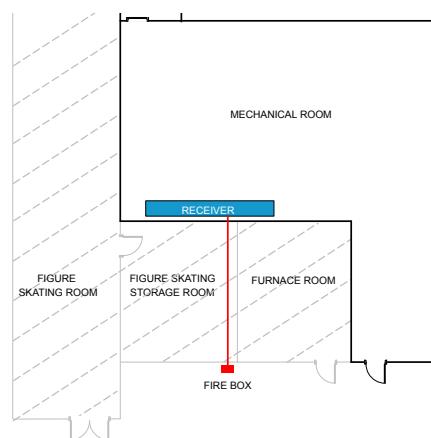


Figure 17 (left):
emergency discharge piping routed through figure skating club storage closet.



Photo 18 (above): Emergency discharge piping routed through concrete wall of closet used to hang storage item.

CONCLUSIONS

Technical Safety BC concludes that the equipment failure was caused by a small hole in the curling chiller carbon steel tube resulting from corrosion at a weld seam. Contributing to this failure and the release of ammonia was the:

- chiller age and corrosive potential of the chemicals and materials used;
- presence of tube weld seam fusion defects;
- isolation of the curling brine expansion tank;
- isolation of liquid ammonia within the leaking chiller; and
- unsupported coupling joints on the brine system pipe.

Technical Safety BC concludes that the incident was caused by a decision to operate the leaking curling chiller. Contributing to this decision was a failure to replace the aging chiller after it surpassed its recommended operational life-span. The decision and failure to replace the chiller may have been influenced by:

- insufficient hazard awareness relating to leaking chillers and aging equipment;
- omission of component end-of-life strategies from the maintenance plan;
- employee turnover;
- competing organizational and departmental priorities; and
- organizational design of the leisure services department.

After examination of the detection, alarm, ventilation and discharge systems, Technical Safety BC concludes the following:

- the ventilation system could not have prevented a high concentration of ammonia in the mechanical room;
- fan location and condition contributed to ineffective ventilation after the release;
- fan exhaust location and airflow may have directed ammonia toward building openings;
- mechanical room doors presented a path for ammonia to enter arena public areas; and
- the emergency discharge did not reduce the risk or amount of ammonia leakage into the mechanical room while introducing exposure risk.

RECOMMENDATIONS

Based on the findings of this investigation, Technical Safety BC has identified 18 recommendations aimed at preventing a similar occurrence. These recommendations seek improvements to:

- owner maintenance programs and organizational design;
- identification of leak hazards and professional disclosure of such hazards;
- training of owners representatives, operators and mechanics;
- secondary coolant system configuration and construction in anticipation of refrigerant leaks; and
- public transparency and a culture of openness around technical systems.

Additional recommendations are made to improve ventilation system requirements and emergency discharge considerations to reduce the potentially harmful effects following a refrigerant release.



RECOMMENDATIONS ARISING FROM FINDINGS RELATED TO TECHNICAL EQUIPMENT

Recommendation 1 to Canadian Standards Association (CSA):

Include design, configuration and condition requirements into CSA B52-13 to ensure the secondary coolant portion of a system can safely withstand the effects of a refrigerant leak.

- Consider the increased pressure and rate of pressure increase from foreseeable refrigerant leaks.
- Address the risk of over-pressurization by operator selected configurations.
- Provide for a safe configuration of the chiller/heat exchanger when a leak is discovered.
- Consider a means to monitor the secondary coolant for developing hazardous conditions in the event of a refrigerant leak.
- Consider compatibility of refrigerant contamination of the secondary coolant system.
- Consider direct ventilation of the brine expansion tanks and secondary coolant system outside of the mechanical room.



RECOMMENDATIONS ARISING FROM FINDINGS RELATED TO OPERATIONAL DECISIONS

Recommendations to improve maintenance programs

The maintenance plan included periodic maintenance tasks but did not consider component wear-out or end-of-life. The maintenance plan was found to be similar to plans at some other arenas.

Recommendation 2 to Arena Owners:

Implement a refrigeration system maintenance program that addresses:

- **Wear-out / End-of-Life** - utilizes an established maintenance end-of-life strategy;
- **Resources** - organizational resource commitment for significant maintenance activity;
- **Approval & Accountability** - program is approved and monitored by the owner, separate from the responsible manager.

Note 1: Product quality defects or lower quality manufacturing methods that could manifest as wear-out failures, such as low-frequency electric resistance welded tubes, should be taken into consideration for component end-of-life planning.

Note 2: Maintenance programs should be developed with professionals that have training and qualifications associated with maintenance life-cycle strategies and condition assessment.

Review of training materials associated with minimum technical qualifications associated with arenas indicated no content relating to brine analysis or interpretation. Refrigeration mechanics identified involvement being limited to drawing samples and passing test results to owners and refrigeration operators.

Recommendation 3 to Training Providers:

Add brine testing, analysis and interpretation to the training and qualifications of refrigeration operators, refrigeration mechanics and 4th class power engineers.

Interview statements were made by some persons involved with refrigeration system management activities that they were not aware of basic system operation and maintenance and were fully dependent upon their mechanic or maintenance contractor for direction. Review of qualification requirements indicates that there are no training or qualification requirements for owners of refrigeration systems.

Recommendation 4 to Arena Owners:

Provide refrigeration system, maintenance program and worker qualification/skill awareness training to all employees and representatives responsible or involved with approving arena maintenance related activities or expenses.

Review of training materials for minimum technical qualifications associated with arena refrigeration systems indicates that maintenance training content did not include component wear-out, end-of-life or condition assessment considerations.

Recommendation 5 to Training Providers (Refrigeration Operators, Refrigeration Mechanics and 4th Class Power Engineers):

Improve training related to maintenance strategies and maintenance program awareness dealing with component wear-out and condition assessment so that graduates can effectively participate with a comprehensive program.

Recommendations to improve hazard awareness of leaking chillers

Evidence did not indicate an awareness of hazard associated with the leaking chiller. Following the incident Technical Safety BC discovered instances at some other arenas where leaking chillers were intended to be operated until replacements could be arranged.

Recommendation 6 to Arena Owners and Maintenance Contractors:

Implement clear procedures that provide guidance and instructions to employees regarding the hazards associated with leaking chillers and required actions.

- *Ammonia detection in brine is evidence of a possible leaking chiller.*
- *Leaking chillers are hazardous.*
- *Chillers suspected of leaking are not to be operated until the condition is assessed as safe.*

Review of training materials indicated that emergency procedures or considerations for such situations were not included.

Recommendation 7 to Training Providers (Refrigeration Operators and Mechanics):

Develop and implement generically applicable emergency situational guidance that can be taught and posted within mechanical rooms.

Examples of simple 'SAFE PRACTICE' instructions for consideration:

- *DO NOT operate equipment that is suspected to be failed/leaking.*
- *DO NOT isolate liquid refrigerant within suspected failed/leaking equipment.*
- *DO NOT isolate secondary coolant systems without pressure relief.*

The condition of a leaking chiller did not receive a clear disclosure that it may be a cause for concern.

Recommendation 8 to Refrigeration Maintenance Contractors:

Implement procedures for employees interacting with owners and operators to clearly disclose and refer items that are a cause for concern to refrigeration professionals with the necessary training to provide advice.

Maintenance contractors are reminded of their obligation to [report hazards](#) that are not known to be addressed by the owner.

Review of communications found that the owner's representative requested advice from persons that was beyond their scope of training and qualification. Evidence also indicated that knowledge of the leaking chiller remained limited to a small number of persons that did not have training or qualifications associated with condition or risk assessment.

Recommendation 9 to Arena Owners:

Implement training and procedures for refrigeration system managers to identify the limitations of different technical qualifications associated with refrigeration systems and engage independent advisors for items considered a cause for concern.

Review of asset management planning and guidance documents found that safety risk assessment was not considered a risk factor, equivalent to financial and service delivery risks.

Recommendation 10 to Local Governments that Own Refrigeration Systems:

Incorporate safety risk assessments into asset management planning activities for all arena and curling refrigeration systems and mechanical rooms.

Safety risk assessments should be completed by an independent professional trained in refrigeration condition assessment methods.

Recommendations to improve refrigeration system management organizational design

Evidence and interview statements indicated that the director responsible for the refrigeration system had a very broad scope of responsibility, with no management support. The director of leisure services was responsible for some competing priorities such as service delivery, maintenance of the refrigeration equipment and the associated facilities.

Recommendation 11 to Local Governments:

Conduct an assessment of the organizational design and assigned resourcing for positions that are accountable for technical system management.



RECOMMENDATIONS ARISING FROM FINDINGS RELATED TO VENTILATION AND DISCHARGE SYSTEMS

An airflow test revealed airflow patterns specific to the installation that resulted with ineffective ventilation and a potential for exhaust to flow towards building openings.

Recommendation 12 to Arena Owners:

Conduct an assessment and test of ventilation systems to evaluate effective internal ventilation of the mechanical room and external discharge in a manner that minimizes risk of exposure.

The additional fan capacity was installed to meet the requirements of CSA B52-13 which defines a total capacity based upon the amount of refrigerant.

Recommendation 13 to Canadian Standards Association:

Implement leak rupture ventilation requirements into CSA B52-13 that consider leakage scenarios, system performance and airflow within and outside of the mechanical room.

- *Fan locations consider airflow within the mechanical room from inlets to exhaust fans, to minimize refrigerant accumulations and time required to exhaust.*
- *Fan locations exhaust refrigerant directly into outside airstream and consider effects of surrounding structures and outside airflow.*

An airflow test revealed airflow patterns specific to the installation that resulted with ineffective ventilation and a potential for exhaust to flow towards building openings.

Recommendation 14 to Canadian Standards Association:

Implement a requirement into CSA B52-13 to assess and verify by test that the ventilation systems effectively exhaust the mechanical room and externally discharge exhausted air in a manner that minimizes the risk of exposure.

The emergency discharge system introduced risk at the Fernie Memorial Arena while its activation did not reduce the risk of ammonia leakage into the mechanical room following the event.

Recommendation 15 - to Canadian Standards Association:

Re-evaluate the intended purpose of the emergency discharge provisions of CSA B52-13 Annex B and consider eliminating it from the code or discouraging its use.

A detailed examination of the routing of emergency discharge piping discovered a charged pipe routed within a public space, which presented a risk to public safety.

Recommendation 16 - to Arena Owners:

Inspect all emergency discharge piping and confirm that routing does not enter any spaces that present a risk to public safety.

Examination of refrigeration operator training materials found explanations associated with operation of the emergency discharge system either missing or promoting risk assessment to occur during the emergency response with only broad guidance relating to the objective of the system use.

Recommendation 17 - to Training Providers:

Review and amend guidance relating to the operation of an emergency discharge system such that specific scenarios where the benefits outweigh the risks are clearly identified and the necessary information to perform an emergency risk assessment is identified.



RECOMMENDATION TO ENHANCE PUBLIC TRANSPARENCY AND SUPPORT A CULTURE OF OPENNESS AROUND TECHNICAL SYSTEMS

A recurring theme in this report is that critical information respecting the technical equipment involved was not made available to all relevant persons interacting with, responsible for, or potentially impacted by the equipment. Most significantly, the investigation discovered that awareness of certain aspects relating to the management of the aging chiller following the 2010 contractor recommendation and the leaking condition of the curling chiller in 2017 remained limited to only those directly involved.

Recommendation #2 strives to have owners implement maintenance programs that plan for wear-out and major expenses, demonstrate organizational commitment to schedule major expenses associated with that program, and monitor their performance in managing the maintenance program. Further, the following recommendation addresses how local governments, arena owners, and Technical Safety BC can provide support.

Recommendation 18 – to Local Governments, Arena Owners, and Technical Safety BC:

Make publicly available the following information associated with management and oversight of regulated refrigeration systems at public assembly facilities (such as arenas):

- refrigeration system maintenance programs for regulated equipment;
- related capital budgeting plans for supporting maintenance programs;
- assessment and audit criteria;
- results of assessments and audits;
- independent recommendations relating to the condition of equipment, including recommendations from maintenance contractors for repair or replacement; and,
- any other information relevant to the assessment, audits and overall safety of the technical equipment and its management programs.