WORKSAFE BC
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INCIDENT INVESTIGATION REPORT

Information about identifiable individuals has been redacted in accordance with the Freedom of Information and Protection of Privacy Act [RSBC 1996]

Type of occurrence **Exposure to/contact w/ hazardous substance/environment**		
Notice of incident number **2017160530032**	Incident outcome **Fatals (3)**	Date of incident **October 17, 2017**
Location of incident **Fernie Memorial Arena 991 6th Avenue Fernie, B.C.**	Lead investigator **Nigel CORDUFF**	Investigation file number **FSI-REG-2017-0123**
Approved by manager, Fatal and Serious Injury Investigations **Jeff YOUNG**	Signature	Date Aug. 22/2018

PARTIES INVOLVED IN INCIDENT

Employer	Name and address **City of Fernie PO Box 190 Fernie BC V0B 1M0**	Employer ID **438**	Industry classification **753004 Local Government and Related Operations**
Workers	[redacted]	**Deceased**	Occupation [redacted]
	[redacted]	**Deceased**	Occupation [redacted]
Employer	Name and address **Toromont Industries Ltd. *doing business as* CIMCO Refrigeration 65 Villiers St Toronto ON M5A 3S1**	Employer ID **9215**	Industry classification **721008 Commercial Refrigeration or Commercial Air Conditioning Work**
Worker	[redacted]	**Deceased**	Occupation **Refrigeration mechanic**

Persons mentioned in report

Name	Known in the report as	Role in the incident/investigation
[redacted]	[redacted]	Employed by Fernie. Was the [redacted] — [redacted] in charge of ice production at Fernie Memorial Arena. Was fatally injured in the incident.
[redacted]	[redacted]	Employed by Fernie. [redacted] in charge of ice production at Fernie Memorial Arena. Was fatally injured in the incident.
[redacted]	Refrigeration Mechanic	Employed by Toromont Industries Ltd. (CIMCO Refrigeration). Was dispatched to conduct maintenance at Fernie Memorial Arena and was fatally injured.
[redacted]	Refrigeration Supervisor	Employed by Toromont Industries Ltd. (CIMCO Refrigeration). Direct supervisor of the Refrigeration Mechanic. Received updates and gave direction via phone the morning of the incident.
[redacted]	CIMCO Sales Representative	Employed by Toromont Industries Ltd. (CIMCO Refrigeration). Was involved in business discussions with [redacted] regarding maintenance and replacement of the refrigeration system equipment.
[redacted]	CAO	The Chief Administrative Officer for Fernie. The [redacted] reported to him.
[redacted]	Rink Attendant 1	Employed by Fernie. Worked in Fernie Memorial Arena [redacted]
[redacted]	Rink Attendant 2	Employed by Fernie. Worked in Fernie Memorial Arena and performed duties in the compressor room.
[redacted]	Rink Attendant 3	Employed by Fernie. Worked in Fernie Memorial Arena and performed duties in the compressor room.
[redacted]	Witness	Smelled ammonia two blocks away from Fernie Memorial Arena after the incident.
[redacted]	Curling Club [redacted]	Smelled ammonia near the compressor room after the incident.
[redacted]	Curling Club [redacted]	[redacted]
[redacted]	Electrician	First to observe the workers unresponsive after the incident. Removed [redacted] and called 911.

Other parties mentioned in report

Name	Known in the report as	Role in the incident/investigation
Royal Canadian Mounted Police	RCMP	Police agency with jurisdiction over the incident - conducting a parallel investigation.
Technical Safety BC	TSBC	An independent safety authority with jurisdiction over the refrigeration equipment. Conducted a parallel investigation.
Acuren Group Inc.	Acuren	Conducted a Curling Rink Refrigeration System Component Failure Evaluation and report for WorkSafeBC and TSBC
Strong Refrigeration Consultants Inc.	Strong Refrigeration	Retained by WorkSafeBC to consult as subject matter experts for refrigeration – provided a report to WorkSafeBC
Startec Refrigeration Services Ltd.	Startec	Was the previous refrigeration contractor for Fernie prior to CIMCO
LEES+ASSOCIATES	LEES+ASSOCIATES	Generated a report for Fernie called City of Fernie Leisure Services Master Plan
Paladin Technologies	Alarm monitoring company	Receiving station for ammonia detector/alarm system at the Fernie Memorial Arena.
Cook's Electrical Service Ltd.	Electrician	Provided electrical repairs to Fernie- employer of the Electrician who first discovered the incident.

Scope

This incident investigation report sets out WorkSafeBC's findings with respect to the cause of and underlying factors leading to the workplace incident that occurred on October 17, 2017, at the Fernie Memorial Arena in Fernie, British Columbia. The purpose of this report is to help employers and workers understand the factors that contributed to the tragic incident so that similar incidents can be prevented in the future.

This investigation report may include some of the enforcement action taken under the *Workers Compensation Act* and the Occupational Health and Safety Regulation in response to the incident and as a result of the investigation. Regulatory compliance activities may be summarized here but will be documented separately.

How the investigation was conducted

WorkSafeBC's Investigations Department conducts health and safety investigations using a systematic approach based on the scientific method. This process involves collecting information from various sources to understand the facts and circumstances of the incident and analyzing that information to identify causal and underlying factors that led to the incident.

The field investigation generally includes the following:

- Securing and examining the incident site, including any equipment involved
- Taking notes and photographs
- Interviewing people with relevant information, such as employer representatives, supervisors, workers, and witnesses
- Collecting documents such as equipment operating manuals, written procedures, and training records
- Conducting tests of materials or equipment, if necessary

The analysis of the information usually includes the following:

- Determining a sequence of events
- Examining significant events for unsafe acts and conditions
- Exploring the underlying factors that made the unsafe act or condition possible
- Identifying health and safety deficiencies

Contents

Incident synopsis

At the Fernie Memorial Arena, workers were performing maintenance on the ice plant when there was a release of ammonia gas. Three workers were fatally injured from exposure to the ammonia.

1 Incident details

1.1 Parties involved

1.1.1 City of Fernie

The City of Fernie (Fernie) is located in the East Kootenay region, near the southeastern edge of British Columbia, approximately 50 km from the Alberta border. Fernie is home to over 5000 permanent residents and usually experiences population increase during the winter months due to the high popularity of winter sports in the region.

Fernie's Leisure Services Department owns and operates all indoor and outdoor recreation facilities, parks, and trails within the city limits, including the Fernie Memorial Arena, where the incident occurred. The Fernie Memorial Arena is centrally located in the city and is approximately one city block in size (see Figure 1).

Figure 1: *Composite image showing the location of Fernie and Fernie Memorial Arena (inset), where the incident occurred. (Source: Google Earth. Imagery © 2018 DigitalGlobe, Province of British Columbia. Map data © 2018 Google.)*

The Fernie Memorial Arena is used for activities such as recreational skating, hockey, curling, figure skating, banquets, and graduation ceremonies. Fernie owns and operates the ice-making equipment at Fernie Memorial Arena.

1.1.2 Toromont Industries Ltd. (CIMCO Refrigeration)

Toromont Industries Ltd. operates as CIMCO Refrigeration (CIMCO), a commercial refrigeration company that specializes in the design, engineering, fabrication, installation, and servicing of industrial and recreational refrigeration systems. At the time of the incident, CIMCO had a service agreement with Fernie for CIMCO to conduct maintenance and provide emergency services for Fernie Memorial Arena.

1.2 Workers

[redacted] was an employee of Fernie for [redacted] years. [redacted] On the day of the incident, he attended Fernie Memorial Arena to respond to the ammonia gas leak.

[redacted] was employed by Fernie for [redacted] years [redacted] On the day of the incident, he was in communication with the Refrigeration Supervisor to troubleshoot the ammonia gas leak.

The Refrigeration Mechanic was employed by CIMCO [redacted] On the day of the incident, he was

dispatched by the Refrigeration Supervisor to attend Fernie Memorial Arena to perform an oil change on the compressors in the compressor room.

The Refrigeration Supervisor had been an employee of CIMCO for [redacted] years, [redacted] On the day of the incident, he dispatched the Refrigeration Mechanic to Fernie Memorial Arena to perform emergency service work and coordinated that work with the [redacted] via phone from his location in Alberta.

Rink Attendant 1 has been employed by Fernie since [redacted] responsibilities include maintaining the arena and performing plant checks. [redacted]

Rink Attendant 2 had been employed by Fernie for [redacted] responsibilities include performing minor maintenance of the ice plant, cleaning the ice, and janitorial duties. [redacted]

Rink Attendant 3 had been employed by Fernie for [redacted] years, including approximately the last [redacted] working in Fernie Memorial Arena. [redacted] responsibilities include operating the ice-resurfacing machine (Zamboni), checking the plant and compressor room every few hours, and recording any issues in the maintenance logbook.

1.3 Workplace

The Fernie Memorial Arena is over 50 years old and includes a curling rink as well as a hockey rink. The normal operating season for ice to be installed in the curling rink is from October 16 to March 15 every year. The incident occurred the day after the curling rink ice-making (refrigeration) equipment was started for the 2017–2018 season.

The incident took place in a room in the support complex between the curling rink and the hockey rink. This room houses the refrigeration equipment — the system components and piping required for ice making — and is referred to as the *compressor room* in this report.

1.3.1 Compressor room overview

The compressor room comprises a main room that houses the majority of the refrigeration equipment, as well as a smaller entrance room to the southeast. The entrance room contains a workbench, tools, and spare parts and is separated from the main room by a steel mesh wall fitted with a lockable steel mesh door. (See Figure 2.)

At the northwest end of the compressor room is a second entrance/exit that leads to the vestibule, which houses equipment controls, an eyewash station, and an emergency deluge shower. On the southwest side is a set of double doors that were found by WorkSafeBC investigators to be sealed and bolted shut.

There are three emergency stop buttons for the refrigeration system: one in the vestibule room, one at the 6th Avenue exit, and one outside of the room next to an emergency discharge valve, which connects to the ammonia vent stack.

All three of the fatally injured workers were found unresponsive in the main compressor room.

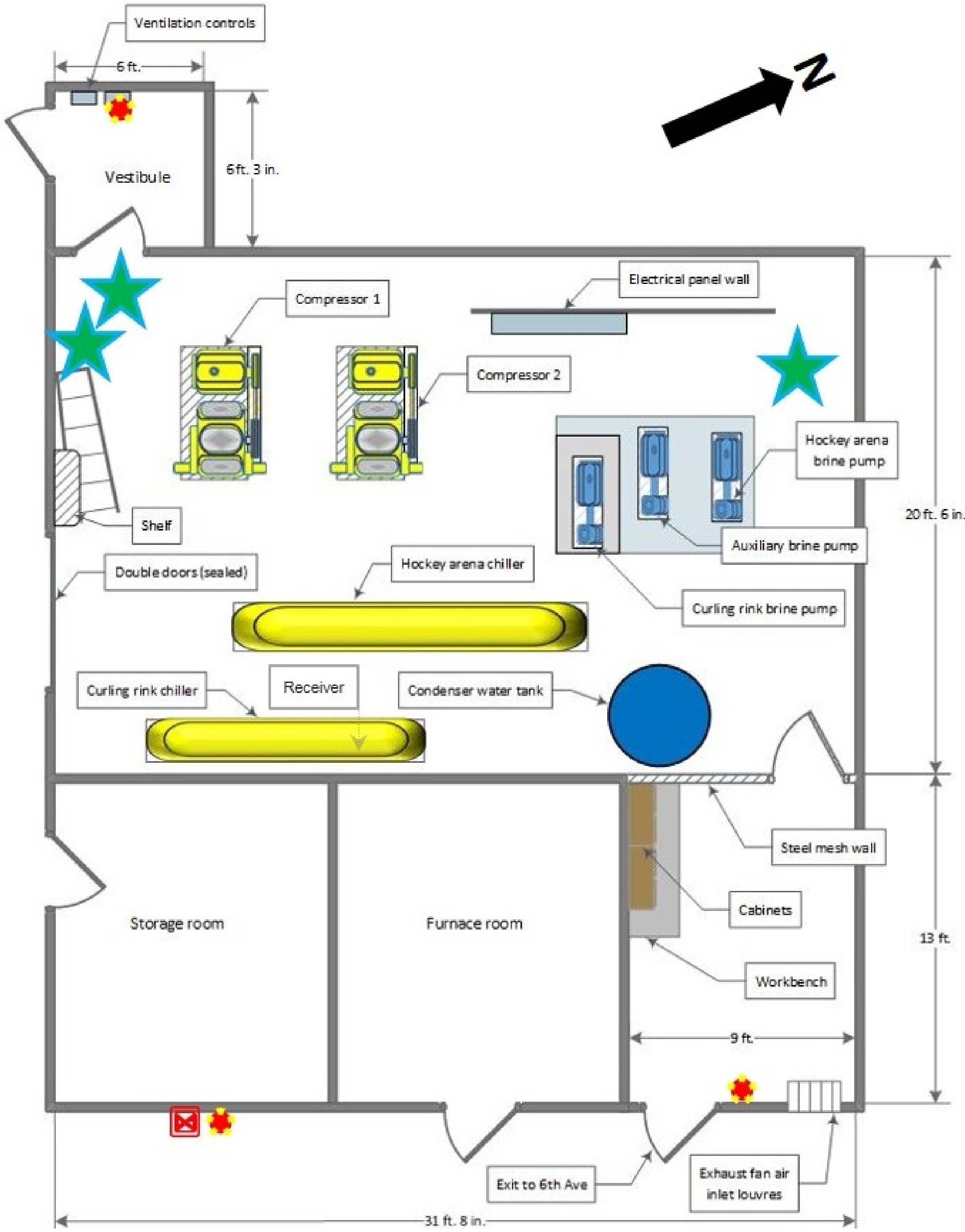

Figure 2: *Overhead view of the compressor room. The fatally injured workers (green stars) were located next to the vestibule door and the brine pumps. Emergency stop buttons (red symbols) were located at both exits and next to the emergency ammonia discharge valve (red box) located outside of the compressor room on the storage room wall. Diagram is not to scale.*

1.3.2 System elements

In this report, the equipment in the compressor room will be referred to as the *refrigeration system.* The refrigeration system comprises five distinct systems, all of which are required for the ice-making process:

- Electrical service, which includes motor control centres, circuit breakers, fuse panels, and equipment control switches
- Water circulation and conditioning system for the ammonia condenser
- Glycol cooling system for cooling the oil used in the ammonia gas compressors
- Ammonia circulation system
- Brine circulation system

The systems that were primarily involved in the incident were the ammonia circulation and brine circulation systems.

1.3.3 Ammonia circulation system

Ammonia is the primary refrigerant used in the facility. It is a highly toxic and reactive substance that is also corrosive, flammable, and can be explosive under certain conditions. (See Appendix A: Safety Information about Ammonia.)

The main components associated with the ammonia circulation system are two gas compressors, the hockey rink chiller, the curling rink chiller, and the receiver tank (receiver). The two compressors and the receiver work together to serve both the hockey rink chiller and the curling rink chiller; one compressor is not allocated to either chiller. (See Figure 3. Note: The alphanumeric labels on the photographs — 1, 2, and A, B, etc. — are sequential and continuous throughout this report. For example, an item marked “1” is the same item marked “1” in any photograph.)

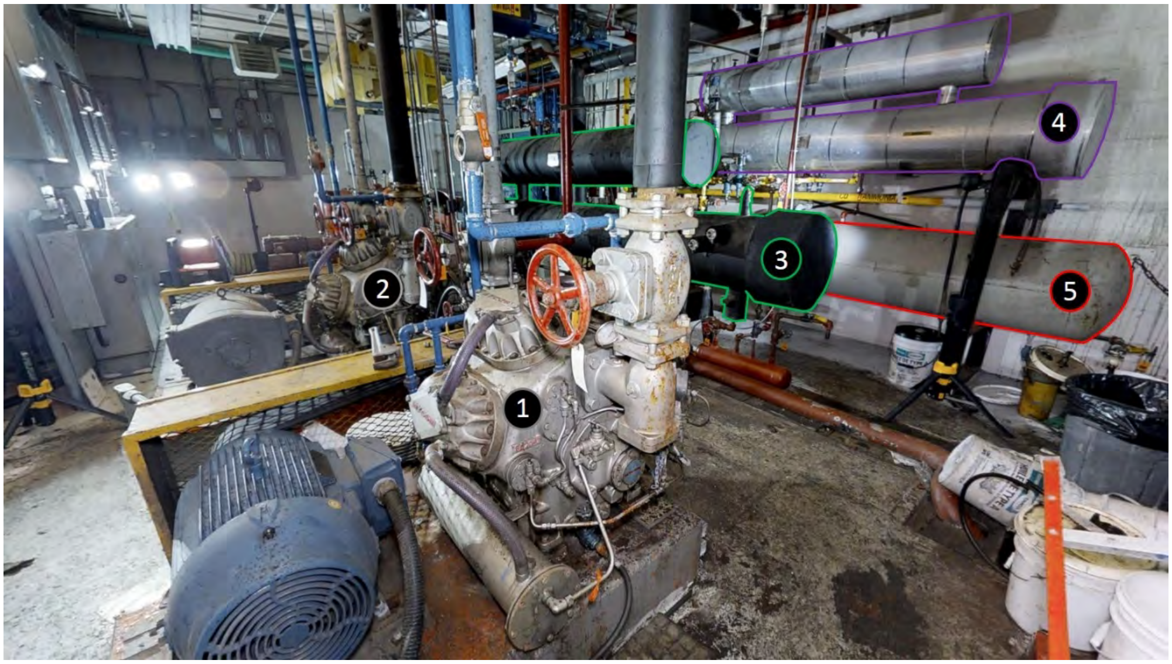

Figure 3: *The compressor room, looking east, showing compressor 1 (1), compressor 2 (2), the hockey rink chiller (3 — green outline), the curling rink chiller (4 — purple outline), and the receiver (5 — red outline).*

The ammonia circulation system is specifically designed to contain ammonia in both liquid and gaseous states. No person is permitted to work on such a system without specialized training and certification as a refrigeration mechanic or higher as per the regulations that describe the legal requirements for contractors working in the technologies regulated by Technical Safety BC.[1] The ammonia system is fitted with mechanical safeguards and specialized valving intended to prevent a leak of ammonia and/or to vent ammonia to the outdoors (to atmosphere) in the event of an emergency.

Ancillary to the ammonia circulation system is a compressor oil loop (not marked in Figures 2 and 3). The purpose of the oil is to act as a lubricant for the prevention of excessive wear and corrosion in the two gas compressors and other parts of the ammonia system. The oil circulates along with the ammonia and is collected at intervals in reservoirs located in the ammonia circulation system. The collected oil recirculates back to the compressors from some of the reservoirs and is stored for secondary disposal or reuse in other reservoirs. It is normal for the compressor oil to be contaminated with ammonia in this type of system.

[1] See the Technical Safety BC website for more information: technicalsafetybc.ca/regulations

1.3.4 Brine circulation system

The heat transfer fluid used in the compressor room is an aqueous brine mixture composed of water and calcium chloride salt. Although corrosive, the mixture is analogous to strong salt water and does not include the wide range of physical hazards presented by ammonia (the refrigerant).

The brine circulation system is a non-pressure-rated system. No special certifications are required for a worker to perform tasks or maintenance associated with the brine circulation system.

The main components associated with the brine circulation system are the hockey rink brine pump, the auxiliary brine pump, the curling rink brine pump, and the two brine expansion tanks. (See Figure 4.)

Figure 4: *The compressor room, looking south, showing the hockey rink brine pump (6), the auxiliary brine pump (7), the curling rink brine pump (8), the hockey rink brine expansion tank (9), the curling rink brine expansion tank (10), and the curling rink brine filter (11). The hockey rink brine filter is not shown.*

The circuit of fluid out of the compressor room to the ice sheets and back is referred to in this report as the *brine loop*. There were two distinct brine loops in this case. Under normal conditions, the hockey rink brine pump (item 6 in Figure 4 above) exclusively services the hockey rink ice sheet and circulates brine back through the hockey rink chiller. The curling rink

brine pump exclusively services the curling rink ice sheets and circulates brine back through the curling rink chiller (Figure 2). Only the curling rink brine loop was involved in the incident.

The auxiliary brine pump (item 7 in Figure 4) can be used if one of the other pumps needs to be taken out of service for maintenance. The valving for the auxiliary pump can also allow for the two separate brine loops to intermix if necessary. On the day of the incident, the auxiliary pump had been isolated from the brine flow by closing four valves, which kept the two brine loops from mixing with each other.

Each brine loop includes a brine expansion tank (items 9 and 10 in Figure 4), which is partially filled with brine. The inlet hole is at the bottom of each tank so that if any air becomes trapped in the brine loops, it can bubble through the supply of brine and into the air space in each tank. The brine tanks are not sealed and are installed so that they vent directly into the compressor room atmosphere.

Each brine loop is also fitted with a brine filter (item 11 in Figure 4). These filters are changed periodically to remove particulate from the brine circulation system. The filters are fitted with drain ports, which allow for periodic sampling of the brine when necessary.

1.3.5 Heat exchanger overview

The chillers are heat exchange devices designed to use the physical properties of ammonia to remove heat energy from the brine, in a closed system. This type of heat exchanger is referred to as a *flooded ammonia chiller*.

The three fundamental states of matter are solid, liquid, and gas. The refrigeration system uses only liquid and gas. When a liquid substance changes state and turns into a gas, energy in the form of heat is pulled from the space surrounding the substance, and subsequently the surrounding area gets cold. Inversely, when a gas is compressed into a liquid, energy in the form of heat builds up and radiates to the surrounding area.

Ammonia has a low boiling point (–33°C/–27.4°F), so it is normally gaseous at room temperature but can be liquefied through cooling, compression, or both. As such, ammonia is ideal as a refrigerant and has been used in the refrigeration industry for making artificial ice surfaces since the 1920s. The refrigeration system uses the cooling effect produced when ammonia liquid turns to gas. This change of state takes place within the ammonia pressure shell of the chillers.

Brine is used as the heat exchange fluid because it has a lower freezing point than water and can be cooled to a much lower temperature without solidifying.

The refrigeration system works by passing warm brine through a bath of ammonia liquid. The liquid brine and ammonia are separated and not intended to mix together as part of the refrigeration process. The brine travels through a group of many small-diameter steel tubes (tube

bundle), which present a large surface area so that contact with the ammonia from the outside surface of the brine-filled tubes is maximized. (See Figure 5.) As the brine passes through, heat is conducted through the walls of the steel brine tubes, which heats the ammonia liquid. The additional heat causes the ammonia liquid to boil into gas, thus cooling the tubes and the brine within.

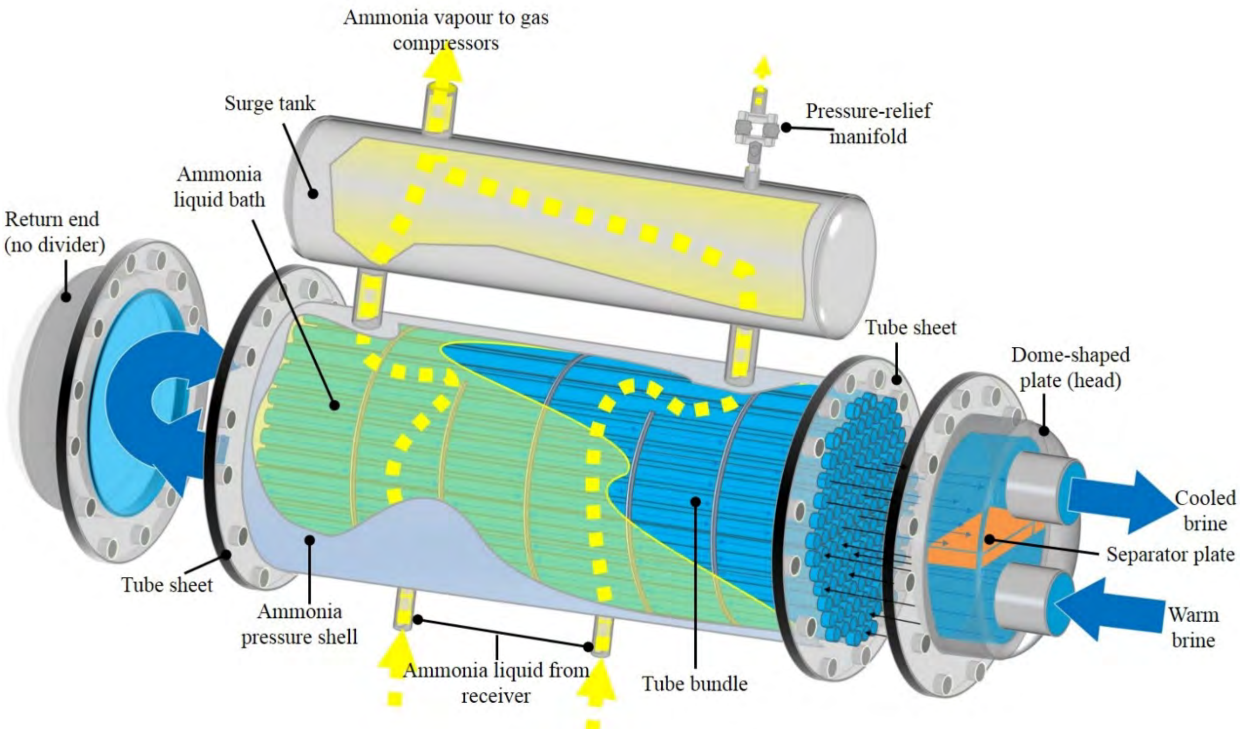

Figure 5: *Simplified diagram of a flooded ammonia chiller. The blue arrows show the circulation path of the brine. The yellow arrows show the circulation path of the ammonia.*

Once boiled, the gaseous ammonia leaves the top of the chiller to be re-liquefied further along in the process. The brine travels out through the top portion of the chiller tubes at a colder temperature than when it entered the chiller.

The brine circulation system and the ammonia circulation system are separated by a steel plate (tube sheet) at each end as well as by the steel tubes in the chiller. The design is intended to prevent the ammonia and calcium chloride brine from coming into direct contact with each other.

The inlet/outlet end of each chiller of this type is a dome-shaped plate (head) divided horizontally by a separator plate. Warm brine is pumped into the bottom of the chiller and forced through the tube sheet. The brine travels through the small-diameter tubes, which are surrounded by the bath of ammonia liquid. The return end of the chiller is another dome-shaped plate (head) without a divider. Hydraulic pressure forces the brine to travel back through the top tubes of the

chiller for another pass through the ammonia bath, and then out as cooled brine to the curling rink ice sheets.

The ammonia pressure shell is positioned between the brine tube sheet plates. Ammonia liquid enters through the bottom of the ammonia pressure shell, and once it boils, the vapour is drawn into the ammonia gas compressors. The curling rink chiller was fitted with a pressure-relief manifold, which was connected to an emergency venting system in the event that an over-pressurization occurs in the ammonia pressure shell.

The ammonia circulation system and the brine circulation system are completely separated from each other mechanically, except within the heat exchange core of the chillers. At these locations, the only separation between the refrigerant and the heat exchange liquid is the 1-inch-thick tube sheet plates and the $^{1}/_{16}$-inch-thick walls of the brine tubes in the core of the heat exchanger.

Both the brine and the ammonia circulation systems circulate continuously while the refrigeration system is operating. (See Figure 6.) Ammonia liquid (red lines) is sent from the receiver to each chiller, where the heat exchange occurs. Low-pressure gaseous ammonia vapour (yellow lines) exits the surge tanks on top of the chillers and is drawn in by the gas compressors. High-pressure gaseous ammonia vapour (purple lines) leaves the compressors and travels to the condenser, where it cools and condenses back into ammonia liquid, which is stored again in the receiver.

Calcium chloride brine (blue lines) is pumped through the chillers and out to a series of tubes embedded in the concrete floor of the ice sheets, allowing the ice to form. In general, both of the brine loops at Fernie Memorial Arena were constructed the same way, with the exception of two bolted, sleeve-type couplings (one vertical — VC; one horizontal — HC) installed in the output end of the curling rink brine loop.

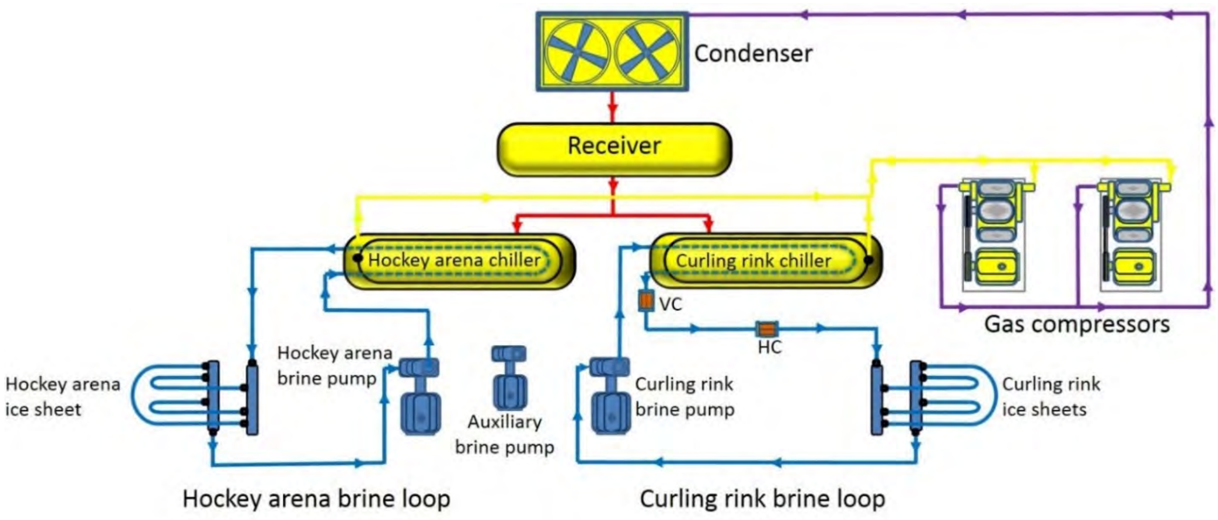

Figure 6: *Flow diagram of the brine and ammonia circulation systems.*

The ammonia used in the compressor room is referred to as *anhydrous ammonia*, which means all of the water has been removed and it is nearly 100% pure. In this form, any free ammonia has a strong tendency to seek out and bond with any available water — including moisture in the air. Anhydrous ammonia is incompatible with (reacts with) copper, copper alloys, aluminum, and zinc.

The amount of ammonia liquid in the chiller is determined automatically by a float switch referred to as the *liquid level control*. To make sure that too much ammonia liquid is not added to the chiller, each chiller is also fitted with an *ammonia liquid high-level shutdown switch*. (See Figure 7.)

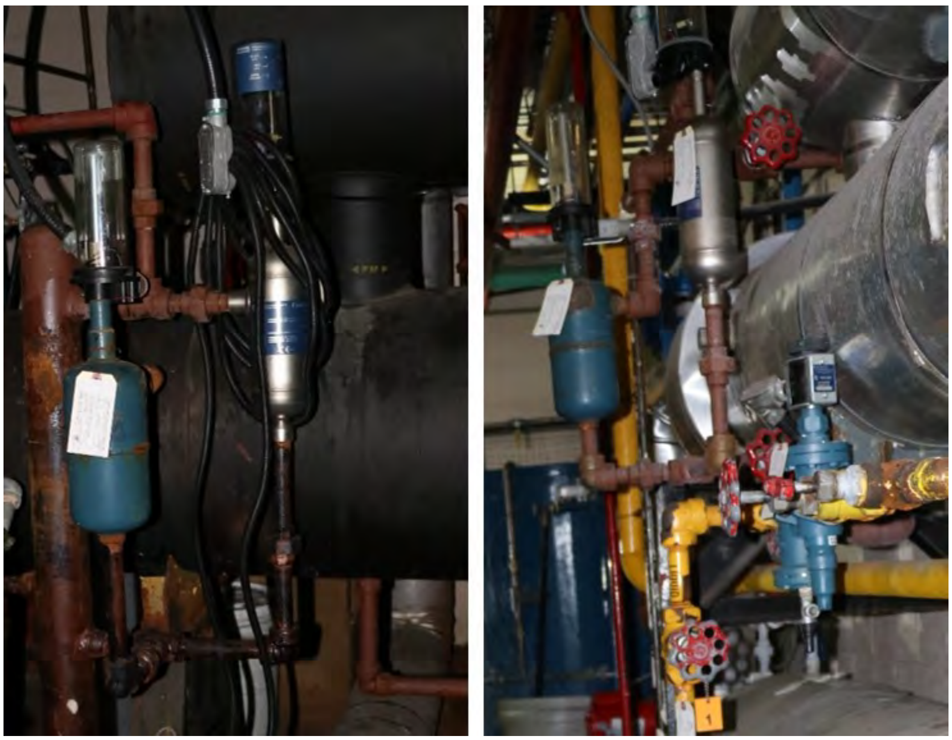

Figure 7: *The photograph on the left shows the hockey rink chiller liquid level control (blue tank) and the ammonia liquid high-level shutdown switch (silver tank). The photograph on the right shows the same control and switch on the curling rink chiller.*

1.3.6 Ancillary equipment

In order for the heat exchange to take place efficiently, it is essential for the different parts of the refrigeration system to be carefully balanced. As such, automatic monitoring components on many of the systems would shut down the system in certain conditions. For example, there are high– and low–ammonia liquid switches on each chiller, high-temperature sensors on the compressors, and high- and low-pressure sensors for the ammonia circulation system. In addition, there are a number of direct-reading pressure gauges available for operators monitoring the system.

Since ammonia (a toxic process gas) is being used, the compressor room is equipped (as required) with an air monitoring system, which includes an electronic ammonia detector and a powered ventilation system designed to activate if ammonia levels in the room are detected within a certain range. The air monitoring system also includes warning lights located in the compressor room and around the facility, including the front lobby of the facility. If ammonia is detected above a defined level, the lights flash orange.

The vestibule outside of the compressor room contains an emergency shower, eyewash, and ammonia gas detector system with a digital readout so that the atmospheric level of ammonia gas in the room can be determined before a worker enters the compressor room. (See Figure 8).

Figure 8: *Composite image showing the ammonia gas detector system located in the vestibule outside of the compressor room.*

In the event that a high ammonia reading is detected, amber warning lights installed around the facility automatically flash, an audible alarm sounds, and an exhaust fan activates. Also, an alarm signal is automatically sent to a monitoring company off site and a separate message is sent to the Fernie fire department dispatch, alerting that an ammonia leak has been detected inside the Fernie Memorial Arena compressor room. It was this system that first alerted the workplace parties that there was a problem in the compressor room in the early morning on the day of the incident.

1.4 Sequence of events

1.4.1 Prior to the incident

The curling rink chiller had been in operation at the Fernie Memorial Arena for approximately 30 years at the time of the incident. The manufacturer does not assign a diary date for life

expectancy of the product. However, the industry norm for service life for this design of chiller ranges from 20 to 25 years.

Fernie had entered into a service and maintenance agreement with a refrigeration firm, Startec Refrigeration Services Ltd. (Startec), which had been conducting normal maintenance on the refrigeration system for years prior to the incident.

On October 5, 2010, Startec sent a proposal letter to Fernie to replace multiple pieces of equipment, including the curling rink chiller. The letter stated:

> This piece of equipment is also past its life expectancy and should be given great consideration on replacing. The average life for this chiller is 20 to 25 years and the age of this unit is at its peak.

Approximately four months later, on January 4, 2011, Startec sent another letter, which stated:

> As per your request, please see work that will be required in the arena ice plant room in the near future. Due to the age of the equipment it is strongly recommended that there be attention to replacing soon before major failure.

In May 2013, Fernie hired a planning and design consulting firm, LEES+Associates, to assess buildings and facilities, including the Fernie Memorial Arena, and develop a document called "City of Fernie Leisure Services Master Plan" (the Master Plan). At that time, no components in the compressor room were assessed to be in poor or critical condition.

In October 2013, the Leisure Services Department published the Master Plan, which identified that due to age, the Fernie Memorial Arena, including the hockey rink and curling rink, were at stage 5 of the BC Recreation and Parks Association classification. According to the Master Plan, this indicates increasing operating costs, a need for significant capital upgrades, increased energy costs, and a decrease in functionality to meet the community needs. Recommendations were made for a replacement facility and equipment to take place over a seven-year period. The Master Plan recommended:

> Until the decision is made regarding a preferred option and timeframe, it is recommended that the City continues to implement basic maintenance and energy-saving strategies, which ensures public and worker safety …

The Master Plan did not include a health and safety assessment or review related to extending the life of the refrigeration system. Fernie did not follow up with any additional risk assessment or strategies related to public or worker safety associated with operating the refrigeration system. At the time of the incident, there were no active projects in process to replace the facility.

The refrigeration system continued to operate and undergo repairs, which included replacing corroded brine lines, rebuilding the gas compressors, and bypassing the ammonia liquid high-level shutdown switches.

On January 30, 2015, Startec again submitted a quote for the replacement of the curling rink chiller.

On November 10, 2015, the [redacted] toured the compressor room with a Startec representative, and Fernie received another quote for the replacement of the chiller.

On December 17, 2015, Rink Attendant [redacted] reported a strong ammonia smell in the compressor room. The smell went away and was not detected by the automatic ammonia gas detector system.

On January 1, 2016, CIMCO replaced Startec as the contracted service provider. In the following month, two brine sampling reports from CIMCO showed 0 parts per million (ppm) for ammonia in the brine.

On February 10, 2016, correspondence between the [redacted] and the CIMCO Sales Representative includes the statement from CIMCO: “We need to work at keeping the plant operational and see what can be done during [regularly scheduled] shutdown. There are a number of issues of concern.”

In February 2016, CIMCO supplied quotes for the replacement of both chillers and other equipment in the compressor room.

In April 2016, the ice plant was shut down as regularly scheduled.

In July 2016, CIMCO rebuilt the two gas compressors and installed a compressor cooling unit. Neither of the chillers was repaired or replaced.

During August 2016, high ammonia readings were detected by the automatic monitoring system, but the operators did not report any smell. CIMCO supplied and installed a new ammonia detector by October 2016.

In the same period, the auxiliary brine pump tripped breakers and blew fuses, so it was taken out of service and found to be plugged with rust. Additionally, problems with the temperature sensor and alarm were reported by operators. Finally, the curling rink chiller was reported by operators to be making unusual, loud noises when operating.

In October 2016, CIMCO provided an updated quote for the replacement of both chillers. The noise from the curling rink chiller was determined to be caused by the ammonia liquid feed valve (solenoid valve), and repair was deferred until the next seasonal shutdown. However, the noise got worse, and during the next two months, CIMCO also quoted for a replacement auxiliary pump, strainers, and a new feed valve.

On January 27, 2017, the ammonia alarm activated three times. CIMCO was advised but did not attend. The ammonia liquid high-level shutdown switches on the chillers were adjusted by an

electrician. The following day, the ammonia liquid feed valves were replaced on both chillers. The source of the ammonia alarms was not recorded.

During late January and into February 2017, the gas compressors shut down repeatedly. Among other troubleshooting measures, CIMCO recommended raising the setting for the ammonia liquid high-level shutdown switch on the hockey rink chiller.

On February 23, 2017, the ammonia liquid high-level shutdown switch for the hockey rink chiller was purposely disabled by an electrician with the knowledge [redacted].

On March 1, 2017, representatives from the Leisure Services Department toured the compressor room. No report was completed.

On April 13, 2017, shutdown began on the curling rink chiller and brine loop. The liquid ammonia was pumped out of the chiller and stored in the receiver. Rink Attendant 2 and Rink Attendant 3 noticed the smell of ammonia when they were changing out the brine filters for the curling rink brine loop. The ammonia smell was not normal, and they reported the issue to the [redacted] and entered the observation in the maintenance logbook.

On May 11, 2017, a brine sample was taken from the curling rink brine loop for analysis. The results were provided to Fernie via CIMCO from an independent laboratory. On June 6, 2017, the independent laboratory forwarded the brine report to CIMCO, and CIMCO then sent the results to Fernie via email. The report indicated that a reading of 3320 ppm of ammonia was present in the brine sample, as well as higher than normal levels of iron, 31ppm. The brine report does not differentiate between iron and iron oxide [rust]. The report included the following statements:

> Please ensure good filtration on this system as iron readings are very high.
> **A significant amount of ammonia was detected in this sample. Please check for possible refrigerant leakage.

On August 1, 2017, CIMCO recommended another brine sample be taken and suggested the "need to monitor" the curling rink brine. There was no discussion about taking the associated refrigeration equipment out of service. Over the next few months, work was performed on the condenser system and the brine expansion tanks in the compressor room. No work was performed on the chillers.

Between August 2 and 4, 2017, CIMCO started up the hockey rink brine loop and refrigeration equipment required to make ice in the hockey rink. A second brine sample from the curling rink brine loop was taken the following day and sent for analysis by a CIMCO representative. Both of the brine expansion tanks were flushed, and sight glasses (level indicators) were installed to provide a visual reference for the level in the tanks. Maintenance work was performed on two pumps in the compressor room, and drain ports were plumbed into the two brine filters.

On August 24, 2017, CIMCO sent another letter of proposed upgrades to the refrigeration system, including replacement of the curling rink chiller, to the [redacted].

On August 29, 2017, the results of the second brine report from the curling rink brine loop were received by CIMCO and forwarded to Fernie. The report again showed high ammonia — 1830 ppm — and higher than normal iron readings at 61.5 ppm in the brine. It should be noted the curling rink brine loop and curling rink chiller had been shut down for several months and were not operating when the second brine sample was taken. As in the first brine report, the second brine report included the same statements noting higher than normal iron levels and the suggestion to check for a refrigerant leak. In both reports, the recommended control range for ammonia in the brine was listed as zero and the range for iron was less than 10 ppm.

There was email communication between [redacted] the Refrigeration Supervisor, and the CIMCO Sales Representative about the results of the brine reports. One of the last communications sent on August 30, 2017 from [redacted] stated: "The curling club test looks bad! The brine line is also really corroded and leaking."

The WorkSafeBC investigation did not find any record of further conversation on the subject between the four workers. No repair work or further testing was conducted on the curling rink chiller prior to the incident.

1.4.2 Day before the incident

On October 16, 2017, [redacted] started the curling rink chiller and brine loop at approximately 06:00 hours.

When the [redacted] left for the day, he instructed [redacted] to stay and monitor the refrigeration system. [redacted] was not informed about the suspected refrigerant leak or the presence of ammonia in the brine. [redacted] noted in the maintenance logbook that between 14:00 hours and 24:00 hours (midnight), compressor 2 made "crazy grinding sounds" at start-up but then later normalized. The oil in both compressors was observed to be cloudy and foamy, which was unusual.

1.4.3 Day of the incident

At five minutes after midnight (00:05) on October 17, 2017, [redacted] checked the automatic ammonia gas detector system and confirmed that it was armed. He called the fire department line to state that he was leaving the arena as per Fernie's working alone policy.

The monitoring company received an alarm from the compressor room at 03:52 hours. The [redacted] and Fernie fire department were called in accordance with alarm procedures. Within 15 minutes, both workers were at the site and the fire department had already arrived. It was a cool evening with a steady wind travelling from west to east.

The firefighters donned self-contained breathing apparatuses (SCBAs) and entered the facility from the front entrance in the north. They used chemical monitors to check for the presence of ammonia in the lobby of the facility. They detected no ammonia but observed the ammonia warning lights were flashing.

[redacted] informed the firefighters that they would need to enter the compressor room to find the source of the alarm. Accompanied by two firefighters, [redacted] entered the compressor room wearing an SCBA loaned by the fire department. The firefighters ensured that a rapid intervention team remained outside of the facility in case of further emergency.

In the compressor room, they observed that all of the refrigeration equipment was running, which made the room very noisy. The brine expansion tanks were shaking, and liquid brine was spilling out of the tops. The ammonia alarm had been activated, and the firefighters obtained a reading of 300 ppm of ammonia from their handheld detection device. [redacted] closed a few valves but left the equipment running. Then they all exited the compressor room.

At approximately 04:24 hours, the [redacted] developed a verbal plan, which the firefighters followed. [redacted] went back into the compressor room with the same two firefighters. [redacted] began to shut down equipment with the local machine controls and close a number of valves in the compressor room. He turned off the pump and both compressor motors. They opened the southeast door to the compressor room to provide some additional ventilation, and then the three workers exited the room for a short time. They went back to the front lobby and obtained a reading of 50 ppm of ammonia. They attempted to reset the ammonia alarm in the front lobby, but the system would not reset and kept coming back on.

A few minutes later, the [redacted] decided to close down the facility for the day. The same three workers re-entered the compressor room, and the [redacted] began closing in the refrigeration system. According to the firefighters, he closed between 12 and 15 more valves, and then they left the compressor room again.

At 04:30 hours, the same group of workers went back into the compressor room and obtained a reading of 50 ppm of ammonia. [redacted] told the firefighters that there were no more worries about anything at that time and that that the system was shut down. The firefighters believed that the system had been isolated.

At 04:48 hours, the [redacted] called the Refrigeration Supervisor, who was in Alberta, and discussed the problem for two and a half minutes. The [redacted] told the Refrigeration Supervisor that the curling rink chiller had let go and that it had been "valved in" [redacted] and that they were going to try to restart the refrigeration system to get the hockey rink ice sheet cooling. Valving in means closing the system components off by closing the valves in the piping that connects them.

The [redacted] informed the firefighters that the curling rink would likely be shut down for the season. He also told them that he and the [redacted] would remain and lock up the facility, that there was no reason for them to remain at the location, and that they could leave. All of the firefighters left soon afterward. During these exchanges, the [redacted] was seen by the firefighters to enter and exit the Facility without an SCBA or other respiratory protection.

At 05:09 hours, the [redacted] was contacted by the alarm monitoring company. He informed them that the fire department was at the site, but did not tell them they were leaving. He also advised the alarm monitoring company to disregard all alarms for the next two hours.

At 05:18 hours, the [redacted] told the Refrigeration Supervisor during a phone call that the gas compressors were not working, that the sight glasses indicated that the oil levels in the compressors were full, and that the oil was foamy. The Refrigeration Supervisor advised that the condition was caused by brine in the compressor oil and that the oil in the compressors would need to be changed out. The Refrigeration Supervisor ordered the appropriate replacement oil and made arrangements to have it couriered to Fernie Memorial Arena.

The Refrigeration Supervisor also called the Refrigeration Mechanic, who was in [redacted], Alberta, and dispatched him to the Fernie Memorial Arena — a travel time of about two and a half hours. The Refrigeration Mechanic was informed by the Refrigeration Supervisor the purpose of the dispatch was to change the oil in the gas compressors.

By 07:31 hours, the alarm monitoring company's two hours had expired. A worker from the electrical contractor that installed the ammonia alarms contacted the [redacted] to let him know that the contractor had been informed of an alarm and asked if they needed a technician to be dispatched. The [redacted] responded that after 16:00 hours they would need an electrician and that the whole alarm system should be shut off. Instructions to the alarm monitoring company were that the system was to be in "test" mode until 16:00 hours, and there should be no dispatches as the system was being worked on.

At 07:49 hours, the Refrigeration Mechanic [redacted] reported that he was in Sparwood, B.C., which is about 22 minutes away from Fernie.

At approximately 08:05 hours, the [redacted] was at Fernie works yard picking up replacement filter cartridges for his air-purifying respirator.

At approximately 09:03 hours, the Refrigeration Mechanic and the Refrigeration Supervisor, who was not on site, spoke over the phone. The Refrigeration Mechanic was just arriving at the site. The Refrigeration Supervisor later stated to investigators that the Refrigeration Mechanic told him there was some compressor oil on site and enough ammonia left in the refrigeration system and that things were looking pretty good for getting the machines going again.

The Refrigeration Mechanic, [redacted] assembled and met at the south entrance of the compressor room. There was consistent phone traffic within the group and to outside parties, including the Refrigeration Supervisor.

The Refrigeration Mechanic, [redacted] entered the compressor room and closed the low pressure input and high pressure outlet valves on compressor 1 in preparation to change out the contaminated oil. [redacted] had any respiratory protection with him, which consisted of a half-mask air-purifying respirator fitted with ammonia vapour filter cartridges.

The last outgoing call from any of the three workers' phones occurred at 09:27 hours. Incoming calls and text messages received by the workers' phones after this time were not answered. WorkSafeBC investigators believe that after 09:27 hours, the Refrigeration Mechanic, the [redacted] were unable to respond because they had been rendered unconscious by ammonia gas that was released unexpectedly in the compressor room.

At approximately the same time, the Witness was getting out of his work van to go into a business located directly east and about two blocks (300 metres) away from the compressor room. The Witness was struck by a very strong smell of ammonia. He did not hear any alarms or sounds coming from the arena. He went into the business location, and when he came out again a short time later, the smell was gone.

At 09:35 hours, the ammonia alarm reading stopped being recorded by the automatic ammonia gas detector system. About 12 minutes later, the [redacted] to enter the curling rink, which is upwind of the compressor room, to do some cleaning after activities not related to this incident. She did not smell ammonia.

At 10:15 hours, the [redacted] approached the compressor room and saw that the door was propped open. When she got to the doorway to go into the compressor room, [redacted]. She returned at 11:00 hours with [redacted] and continued cleaning up the curling rink.

At 12:45 hours, the Electrician, who had been hired to do some work at the facility, arrived at the front doors on the north side and saw a handwritten note stating that the facility was closed for an ammonia emergency. He travelled to the rear entrance off 6th Avenue and observed that the compressor room door was propped open. He smelled ammonia and saw the [redacted] on the floor of the compressor room. He entered the compressor room, dragged the [redacted] out of the compressor room, called 911 at 12:54, and began performing CPR on the [redacted] until emergency services arrived. [redacted] was deceased.

During this time, a courier driver arrived at the location to deliver the compressor oil. The driver called the Refrigeration Supervisor and informed him that there had been an incident at the arena.

At 13:00 hours, Fernie firefighters donned SCBAs and obtained a reading of 400 ppm of ammonia in the compressor room. They observed the Refrigeration Mechanic and [redacted] collapsed in the far corner of the room near the north exit. They were able to quickly ascertain that the workers were deceased.

The firefighters conducted a search of the facility, encountered [redacted] in good health, and instructed them to exit immediately to a safe area. No other injuries were discovered as a result of the ammonia incident.

The ammonia readings in the compressor room continued to rise. At 14:07 hours, an evacuation order of the area surrounding the Fernie Memorial Arena was issued by the fire department. The evacuation order was later upgraded to a seven-day state of emergency by officials.

The Refrigeration Mechanic and the [redacted] were removed from the compressor room the next day, after a safety plan was developed by the Fernie firefighters to prevent any further injury to workers including the emergency responders.

2 Findings

2.1 Incident scene

A WorkSafeBC officer attended the incident location shortly after the emergency was reported to WorkSafeBC. Care and control of the incident scene was initially managed by the Fernie fire department. The incident scene was taken over by the RCMP at 22:45 hours on October 17, 2017. The location was secured from tampering by the use of perimeter fencing and 24-hour security provided by WorkSafeBC.

Fernie contracted Ram Environmental Response Ltd., an environmental remediation firm, to set up air monitoring and conduct initial remediation of the incident scene. This included the cutting and evacuation of the brine pipes outside of the compressor room that fed the hockey rink and curling rink ice sheets. In addition, some of the valve positions on the equipment were altered in order to ensure that there was no further potential impact to public safety.

This work was conducted by trained specialists outfitted with full-body chemical protection and wearing SCBAs. The initial remediation process was documented via digital photographs and video. The video showed that a 4-inch-diameter brine pipe leading from the curling rink chiller had separated and that the floor of the compressor room was covered in black, oily liquid that had sprayed onto the walls, ceiling, and equipment at the west end of the compressor room,

where the curling rink brine outlet pipe had separated. Some of the expelled liquid flowed into floor drains in the compressor room and vestibule. (See Figures 9 and 10.)

Figure 9: *The compressor room, looking southeast, showing the brine outlet pipe that separated at HC (horizontal coupling), located under the hockey rink chiller (3). The black, oily liquid that sprayed out of the separated pipe is outlined by the dotted yellow line. Also shown are compressor 2 (2) and the curling rink brine filter (11). (Orange paint is visible through the top coat of grey paint on the concrete floor.) (Source: Ram Environmental Response Ltd.)*

Figure 10: *Vestibule floor and door. The oily liquid flowed under the door and through the hinge area. The blue colour on the brass floor plate indicates exposure to ammonia.*

The spray of black, oily liquid in the compressor room was confined to the west side of the room and was observed to be vectored from the separated pipe to the west wall. Spray patterns on the ceiling and walls suggest that there was significant volume and pressure involved when the liquid was deposited on the interior surfaces of the compressor room. (See Figure 11.)

Figure 11: *Composite images of the compressor room, showing spray patterns from the separated pipe: Spray on the south wall (A) behind the end of the curling rink chiller (4) and receiver (5) and on the ceiling above the vestibule door at the north corner (B). The brass locks (C) and copper pipe (D) turned blue due to ammonia exposure. Behind compressor 1 (1) is spray and pooling of black liquid on the west wall and floor (E). The paint peeled off the sealed double door (F) after exposure to the ammonia-brine mixture.*

Fourteen days after the incident, area monitoring showed that ammonia levels in the compressor room had dropped. However, a significant risk of exposure to workers remained from trapped ammonia and contaminated system components in the compressor room. The hazard from ammonia in the compressor room remained too high to allow for detailed examination of the incident location.

WorkSafeBC developed a written site-specific safety plan in order to control the hazards to workers for the WorkSafeBC investigative team, as well as other agencies and specialist contractors who required entry into the compressor room to conduct their own investigations: the RCMP, Technical Safety BC, City of Fernie, and CIMCO. The site-specific safety plan included constant area and personal monitoring for ammonia, an entry team specialist to monitor the atmosphere, a rescue team posted outside of the room, a decontamination area, emergency medical personnel on standby, and coordination with the local area hospital prior to each entry into the compressor room. (See Appendix B: WorkSafeBC Site-Specific Safety Plan)

On December 13, 2017, the RCMP was the first investigative team to enter the compressor room. Control of the incident scene was handed over to WorkSafeBC on the evening of December 13, 2017. WorkSafeBC investigators first entered the compressor room on December 14, 2017, and made observations discussed in the remainder of this report.

During the investigation, WorkSafeBC conducted field examinations and took measurements of the equipment at the incident scene (in place) in conjunction with professional engineers and subject matter experts. Additionally, some equipment and parts that could not be tested or examined in place were removed by WorkSafeBC for further examination by Acuren Group Inc. at its independent forensic testing laboratory, which specializes in industrial and metallurgical testing. (See Appendix C: Forensic Engineering Report — Acuren Group Inc.).

Due to the remaining hazards, only a limited number of individuals could be accommodated in the compressor room. A closed-circuit video feed was provided to accommodate viewing by other interested parties outside of the hazardous area during any testing and examination conducted in the contaminated area.

All testing that occurred at the forensic testing laboratory was conducted with the knowledge of the interested parties and agencies associated with the investigation. Input from representatives who attended was received and considered during the testing portion of the investigation.

2.2 Refrigeration system condition

2.2.1 Pipes and valving

Fernie did not have a complete set of up-to-date engineering drawings for the refrigeration system. However, the service provider, CIMCO, had created engineering drawings for the ammonia system as part of the installation of a glycol cooling system for the compressors, which aided all investigators at the initial stages of the investigation.

Once access to the compressor room was possible, WorkSafeBC commissioned the creation of three as-built engineering drawings by subject matter experts to aid in the health and safety planning and provide an overall understanding of the refrigeration system as observed. The WorkSafeBC engineering drawings included the glycol cooling system, the ammonia circulation system, and the brine circulation system. (See Appendix D: Refrigeration Subject Matter Expert Technical Report — Strong Refrigeration Consultants Inc.)

WorkSafeBC investigators used the amalgamated facts from the new engineering drawings, witness interviews, and digital photographs/video taken by first responders to develop a map of the likely valve positions in the compressor room at the time of the incident. Of specific interest was the closed inlet valve to the curling rink brine expansion tank. (See Appendix E: As-found Valve Positions Drawings.)

2.2.2 Cooling systems

The condenser water system used to cool the high-pressure ammonia vapour was visually observed and documented. There was nothing to indicate that the interface of this system may have had an impact or influence on the other systems in the compressor room. Further examination of this system was not conducted, and issues with the condenser cooling system were ruled out as a contributing factor in the incident.

Similarly, the glycol cooling system for the gas compressors was examined and documented. The system was drained and found to contain aqueous glycol coolant. The glycol was found to be uncontaminated with no presence of oil, ammonia, or brine. Subsequent to this examination, a gas compressor coolant failure on the refrigeration system was ruled out as a contributing factor in the incident.

2.2.3 Brine circulation system

During the remediation process, samples were taken of the liquid from each of the brine loops. The hockey rink brine loop did not show any significant levels of ammonia contamination. The samples from the curling rink brine loop showed substantial ammonia contamination with levels recorded as high as 5395 ppm.

All three of the brine circulation pumps were leak-checked, disassembled, and examined at the incident site. No foreign material, broken machine parts, or other obstruction was observed that would prevent any of the brine pumps from operating as intended. It was observed that the curling rink brine loop piping materials that contained copper or zinc alloys had reacted unfavourably from exposure with the ammonia-brine mixture, causing noticeable corrosion or discoloration. This effect was quite pronounced on the copper alloy/bronze impeller for the curling rink brine pump but was not observed on the other two brine pumps, which were isolated from the curling rink chiller. (See Figure 12.)

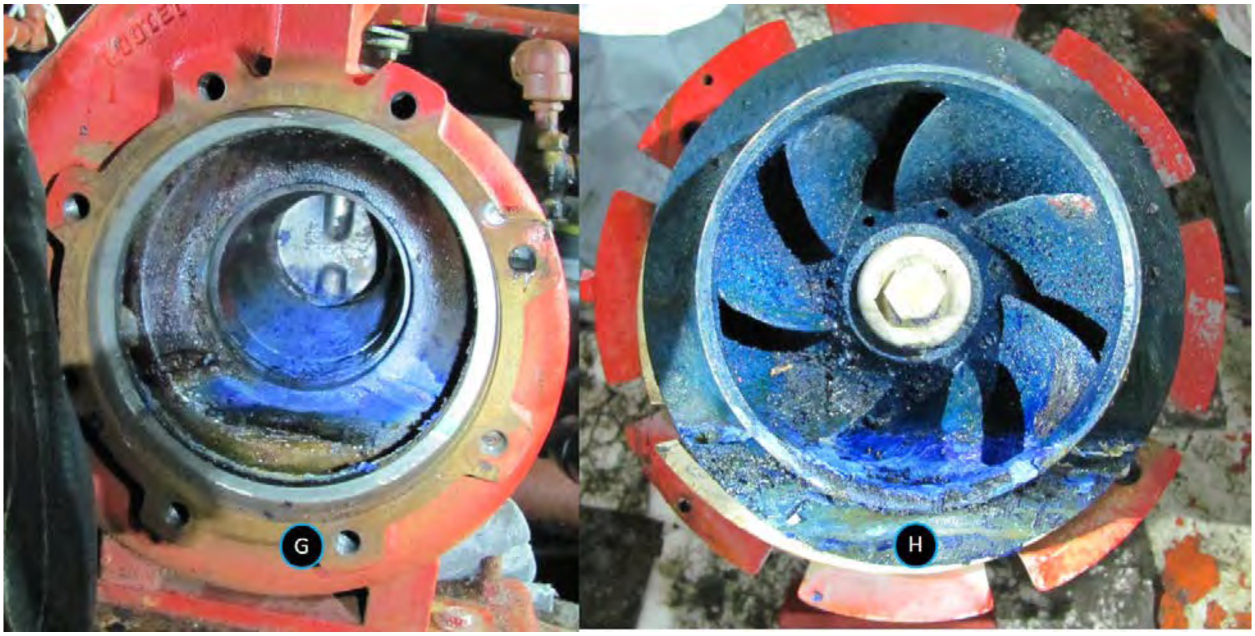

Figure 12: *The interior of the curling rink brine pump housing (G) and the pump impeller (H), showing the corrosive effect of ammonia to some metals in the system, in this case the copper alloy/bronze pump impeller.*

The brine circulation system piping was examined up to the header pipes leading to the ice sheets. The delivery and return piping for each brine loop travelled out of the compressor room in a trench that was sealed on both sides with grout. The header pipes for the brine loops were located outside of the compressor room underneath wooden covers in the publicly accessible areas of the curling rink and the hockey rink. At these locations, it was observed that the brine loop piping embedded in the concrete floors of the ice sheets transitioned from steel to plastic piping. The plastic tubes were connected to steel stumps on the brine header pipes with single compression gear clamps. Although the exterior piping in some of these areas showed substantive surface corrosion, when the header pipes were sectioned for examination, they were determined to be in good condition for their purpose. No leaks or breaches were detected in the piping for either of the brine loops located outside of the compressor room.

All of the brine piping was comprised predominately of schedule 40 steel pipes at diameters between 4 and 6 inches. All of the flanges and joints were welded or bolted connections with the exception of the 4-inch-diameter curling rink brine outlet pipe. At this location, two connections were made using bolted, sleeve-type couplings. One connection was mounted in a vertical position (VC in this report), and the other was mounted horizontally (HC in this report). The pipe that separated at the time of the incident did so at the HC joint. (See Figure 13.)

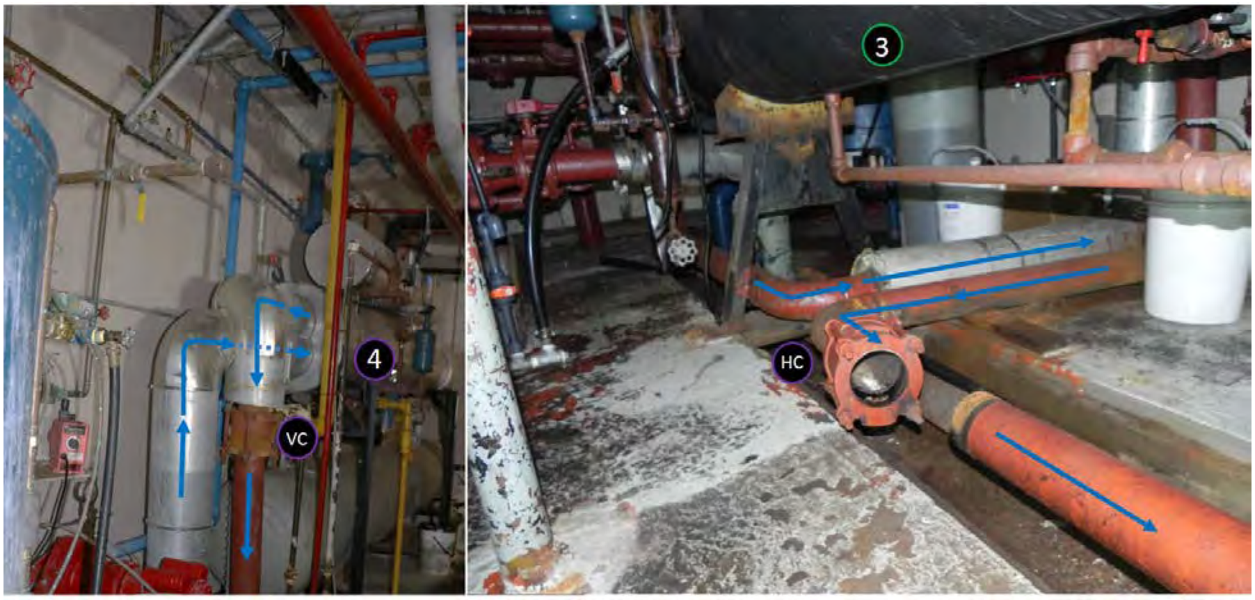

Figure 13: *The photograph on the left shows the position of the vertical coupling (VC) on the brine outlet pipe of the curling rink chiller (4). The photograph on the right shows the horizontal coupling (HC) under the hockey rink chiller (3) and downstream of the VC. The normal brine circulation path is indicated by the blue arrows.*

No records or any other evidence was obtained during the investigation to explain why the two couplings were installed on the curling rink brine outlet pipe, or who installed them. Digital photographs taken at the time CIMCO took over the service contract show the couplings were in place nearly two years, at least, prior to the incident, and all of the piping had been painted orange between that time and when the incident occurred. However, no further information was obtained through document review or witness testimony regarding the couplings.

The couplings were designed to meet ANSI/AWWA (American Water Works Association) standard C219, *Bolted, Sleeve-Type Couplings for Plain-end Pipe*, and were intended to be installed with restraints to prevent pipe movement when the coupling was subjected to pressure. No restraints were used during the installation of either coupling in the compressor room. Without restraints, the piping system is referred to by the coupling manufacturer as "unsupported" and is not intended to withstand any axial loading.

The VC and HC as well as their associated piping were removed from the incident location for further examination and testing at the forensic testing laboratory. In addition, a test rig was constructed using new pressure-rated pipes and a new coupling. The test rig is referred to as the *pipe coupling exemplar* in this report.

The pipe coupling exemplar was assembled and tested in the presence of the coupling manufacturer in accordance with the product instructions. In this case, the manufacturer recommends lubricating the two rubber pipe gaskets with a proprietary lubricant and tightening

the four clamping bolts in an alternating pattern to between 70 and 80 foot-pounds of torque on each bolt, which ensures a good seal. The pipe coupling exemplar was assembled at 75 foot-pounds of torque.

Two tests were performed on the pipe coupling exemplar. The first test involved assembly and installation without gasket lubricant in order to adjust for potential drying out or absence of the gasket lubricant in the couplings obtained from the compressor room. The second test was conducted with the gaskets on the exemplar lubricated as directed.

The results of both tests were similar and showed that when hydraulic pressure was applied, the pipe would move out of the joint, causing the connection to separate at 30 psi in the first test and 25 psi in the second test. It was additionally noted that when the pipe began to move, it would not stop if the pressure remained constant or increased, and that after that point, pipe separation was inevitable.

After the pipe coupling exemplar tests, the exemplar was disassembled and examined. It was observed that significant deformation of the rubber gaskets had occurred. The manufacturer explained that this type of material "flow" was expected and that the rubber gaskets migrate into position after tightening to make the final seal. This process left an identifiable pattern or impression on the rubber gaskets that was apparent after a short period of installation.

The VC and HC from the compressor room were also disassembled. WorkSafeBC investigators observed that the gasket face from the HC assembly removed from the compressor room did not have the same identifiable pattern impression and more closely resembled the new, uninstalled gasket from the pipe coupling exemplar. (See Figure 14.)

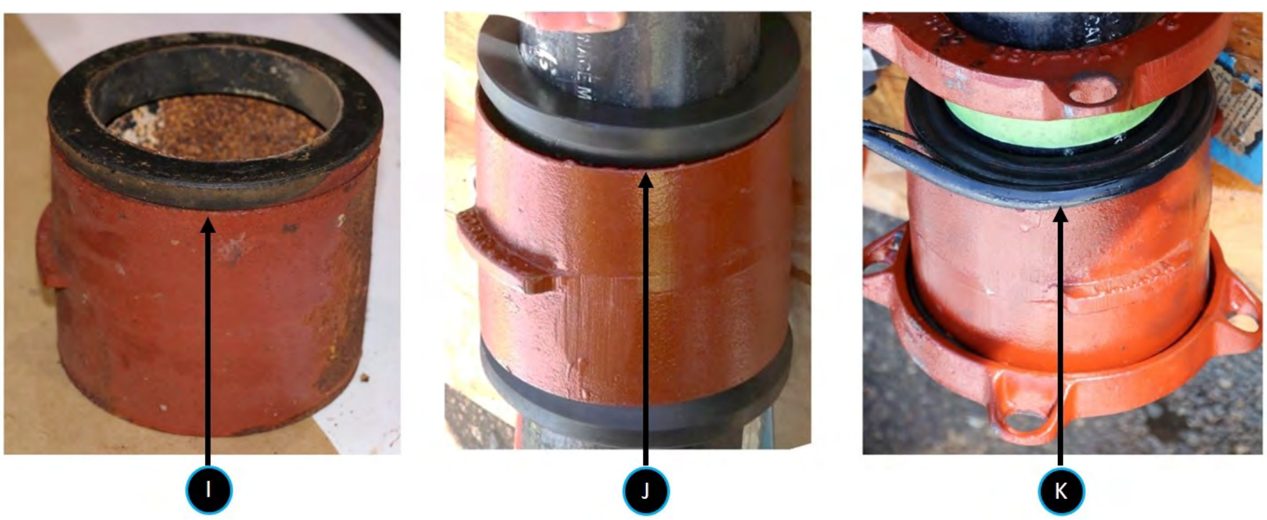

Figure 14: *The HC gasket face as found in the compressor room (I); the new, uninstalled gasket face at the same location on the pipe coupling exemplar (J); and the new gasket less than one hour after being installed as per the manufacturer's instructions (K).*

The clamping bolts for the VC and HC were severely corroded, which likely occurred after the incident and prior to removal from the incident location. However, it was observed that the bolts, if not seized by rust, were relatively easy to undo and did not require 75 foot-pounds to loosen. Additionally, the HC appeared to have been put together using parts from two different models of coupling from the same manufacturer. In summation, no defect was observed in the couplings that could be attributed to a flaw in the manufacturing process.

As a result of the examination and testing, WorkSafeBC investigators determined that the VC and HC installed in the curling rink brine outlet pipe in the compressor room had not been correctly installed in accordance with the manufacturer's recommendations at the time of the incident. Specifically, there were no restraints to prevent the pipes from moving, and the clamping bolts were not sufficiently tightened.

2.2.4 Ammonia system — Condenser and compressors

Although the refrigeration system was powered down, all investigative activity associated with the refrigeration system in the compressor room — including the manipulation of fittings, pipes, and valves and the disassembly of equipment — was conducted exclusively by qualified refrigeration mechanics employed by licensed maintenance contractors as required by the Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation.[2]

The total system charge of ammonia is normally 544 kilograms (1200 pounds). The receiver had a capacity of 1443 pounds of ammonia at 32.2°C/90°F. Subsequently, the combined ammonia from both chillers could have been stored in the receiver, filling it to a volume of 85%. However, there was no reason to pump down the hockey rink (move all or most of the ammonia liquid from the ammonia pressure shell to the receiver for storage), and therefore all of the ammonia from the curling rink chiller could have been stored in the receiver.

The ammonia condenser was located outside of the compressor room. The condenser was visually examined and documented. There is no evidence to indicate that a malfunction of the condenser portion of the system contributed to the incident. No additional testing was conducted on the condenser.

Both of the ammonia gas compressors were examined in place. Maintenance records showed that the compressors had both been torn down and rebuilt on July 6, 2016.

Compressor 1 was located near the west wall and was closest to the north exit of the compressor room, where the Refrigeration Mechanic and the [redacted] were recovered after the incident. There were tools and fittings as well as a stepladder near compressor 1. A wrench, matching the diameter needed to remove ammonia valve covers, was observed on a small shelf next to compressor 1, adjacent to an ammonia valve cover that had been removed. The wrench matched an empty spot in a line of wrenches hanging on the tool wall located at the south door.

[2] www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/17_104_2004

On compressor 1, it was observed that the high- and low-pressure ammonia inlet/outlet valves for the compressor were shut and that two short lengths of flexible tubing had been attached to oil drain ports on compressor 1, with empty drain buckets positioned nearby. On the floor by the south door, a portable vacuum pump fitted with flexible tubing had been placed on the floor.

Compressor 2 was located adjacent to compressor 1 on the east side. The high- and low-pressure ammonia inlet/outlet valves had not been shut on compressor 2, and flexible drain lines had not been installed.

The oil reservoirs for both compressors were drained and found to be overfull of a mixture of ammonia-contaminated compressor oil and brine. Compressor 1 was found to be holding pressurized ammonia after the incident, and it was determined that there was no failure of containment on compressor 1. The same areas of compressor 2 were tested with pressurized nitrogen and also found to have no leaks or loss of integrity.

Each compressor has eight cylinders, located in four banks of two. When the cylinder head covers were removed, substantial crystal growth could be observed in both compressors. (See Figure 15.) The crystalline growth was indicative of brine infiltration into the compressor cylinders, which is an abnormal operating condition. The ammonia gas compressors are not designed to handle any liquid. There was no mechanical connection of the ammonia gas compressors to the brine system. As such, inadvertent misdirection of brine into the ammonia gas compressors should not be possible.

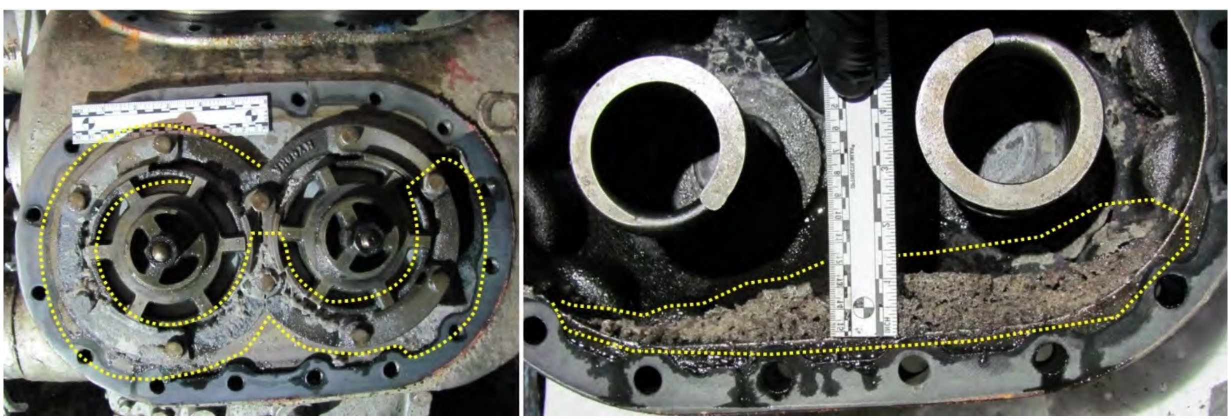

Figure 15: *Crystal accumulation (yellow outline) in the ammonia gas compressor cylinder heads, showing cylinder heads on the left and a cylinder head cover and springs on the right.*

Further examination of compressor 2 was halted, and it was wrapped in place in the event further examination was required. All eight cylinder heads were removed from compressor 1. With the exception of the widespread crystallization, the cylinders, covers, ports, and compressor body were found to be free of defects.

By the examination and testing conducted in place, WorkSafeBC investigators determined that malfunction of one or both of the ammonia gas compressors was not a contributing factor in the incident.

Given the totality of the following evidence collected on the ammonia gas compressors, WorkSafeBC investigators concluded that maintenance work was being performed on compressor 1 just prior to or at the time of the incident:

- Isolation of compressor 1 from the ammonia circulation system had been completed.
- Oil draining lines had been installed in two ports on compressor 1.
- Tools and equipment for an oil change, such as the vacuum pump and buckets, were available and/or arranged near compressor 1.
- No other equipment or component in the compressor room was found isolated or with tools staged for work.
- Two of the fatally injured workers were found in close proximity to compressor 1.
- The Refrigeration Supervisor stated that the task assigned to the Refrigeration Mechanic was to change the compressor oil.
- The oil that the Refrigeration Supervisor had ordered arrived by courier soon after the incident.

2.2.5 Ammonia system — Hockey rink chiller

The hockey rink chiller was built in 1995 by Docal Ltd. The entire chiller was wrapped in black rubberized insulation that appeared to be a product known as Armaflex.

A leak test using nitrogen was performed in place on the hockey rink chiller. The test did not indicate any leaks from the ammonia pressure shell. The ammonia liquid high-level shutdown switch and liquid level control for the hockey rink chiller were tested in place with inconclusive results. These two switch assemblies were removed for testing in the laboratory.

Laboratory results determined that the hockey rink liquid level control was functional, but the ammonia liquid high-level shutdown switch had been defeated by a plastic zip tie and therefore was not functional at the time of the incident. This meant that the entire ammonia pressure shell for the hockey rink chiller could have been filled with ammonia liquid when the chiller was in operation. (See Figure 16.)

Figure 16: *Photograph showing a black plastic zip tie used to defeat the factory setting on the ammonia liquid high-level shutdown switch on the hockey rink chiller.*

The ammonia liquid feed valve for the hockey rink chiller had been manually opened during remediation efforts prior to WorkSafeBC's entry into the compressor room. When examined at the forensic testing laboratory, it was observed that this valve had been corroded internally, likely after the incident, and laboratory testing for function could not be achieved.

Given that no leak was detected and the samples from the hockey rink brine loop came back as negative from ammonia, the hockey rink chiller was left in place, and no further testing was conducted.

2.2.6 Ammonia system — Curling rink chiller

The curling rink chiller was manufactured by Chil-Con Products Ltd. in 1986. The entire chiller and a portion of the curling rink brine loop pipes entering the chiller were clad in sheet metal over polystyrene foam insulation.

As with the hockey rink chiller, the ammonia liquid feed valve for the curling rink chiller had been manually opened by emergency responders and was seized open when laboratory testing

began. No conclusive results regarding the function of the valve could be determined at the laboratory.

The liquid level control and ammonia liquid high-level shutdown switch for the curling rink chiller were tested in place. Both devices appeared to activate within the expected performance limits. They were also removed and delivered to the laboratory. It was determined through laboratory testing that the ammonia liquid level control functioned as designed. As with the hockey rink chiller, the ammonia liquid high-level shutdown switch for the curling rink chiller had been altered from its manufactured setting and raised to increase the amount of ammonia liquid in the chiller, but the switch activated at the higher level when sufficient fluid was added to the float tank.

The liquid level control and the ammonia liquid high-level shutdown switch were an issue as far back as January 2015 and were known by Fernie and CIMCO to have been intentionally disabled since August 2016. An email dated August 11, 2016 from the CIMCO Sales Representative to the [redacted] when discussing deficiencies and repairs to equipment in the compressor room states: “The high level float switches are presently ‘cheated out’ — that is the way we found them, the switch assembly has been raised higher & rendering the controls ineffective …”

The correspondence explains other deficiencies with the piping and inability to lock the liquid level control and the ammonia liquid high-level shutdown switch out, and then goes on to state: “[T]he high ammonia level float switches are there to protect the compressors from drawing in liquid & destroying themselves.”

As outlined by the CIMCO Sales Representative, ineffective function of the ammonia liquid high-level shutdown switches on both chillers could have resulted in sudden equipment failure on or near the ammonia gas compressors. The mode of this failure is unpredictable and could have caused an ammonia release and exposure to workers in the Fernie Memorial Arena in a different manner than what occurred in the compressor room on the day of the incident.

Intentionally rendering safeguards ineffective where worker protection is at issue is prohibited under section 4.12 of the Occupational Health and Safety Regulation. The recommended repairs were not conducted on the ammonia liquid high-level shutdown switches.

As outlined in section 2.2.4 above, WorkSafeBC investigators did not find any evidence that the gas compressors had been damaged from ingesting ammonia liquid. As such, the intentionally disabled ammonia liquid high-level shutdown switches were not a direct contributing factor in the incident. The evidence shows the refrigeration equipment had been operated and maintained previously while system components were known to be in a disabled or otherwise substandard mechanical condition.

The curling rink chiller was fitted with two pressure-relief valves connected to a dual-port manifold (see Figure 17). The manifold was designed so that if flow to one valve was cut off, flow was always provided to the second valve. It was not possible to isolate both valves from flow at the same time. Although the two valves were manufactured at different times, they were both supplied by the same manufacturer and were installed on the same date in August 2015. The pressure-relief valve in service at the time of the incident was examined at the laboratory using high-powered digital microscopes in the presence of manufacturer representatives. There is no evidence to indicate that the pressure-relief valve had opened during the incident. The second pressure-relief valve was tested and found to be operating as intended. The factory-set opening pressure for each valve was 150 psi.

Figure 17: *The pressure-relief manifold installed on top of the surge tank for the curling rink chiller.*

The curling rink chiller was examined in place. The insulated cladding was removed, and the exterior of the chiller showed minimal corrosion on the outside of the ammonia pressure shell. (See Figure 18.) The two dome-shaped end plates (heads) were removed in place. After the heads were removed, all of the gaskets were observed to be intact and in serviceable condition for their intended use.

Figure 18: *The curling rink chiller with the insulated cladding removed.*

Examination of the tube sheet ends showed a substantial buildup of black, oily liquid. (See Figures 19 and 20.) This residue was determined to be the same as the liquid that had been found sprayed around the west end of the compressor room, where the brine outlet pipe had separated. The accumulation of black liquid was more pronounced in the lower hemisphere of the curling rink chiller than the top hemisphere. In some cases, the brine tubes appeared to be completely blocked, which may have reduced the efficiency of the heat exchange process in the chiller when it was in operation.

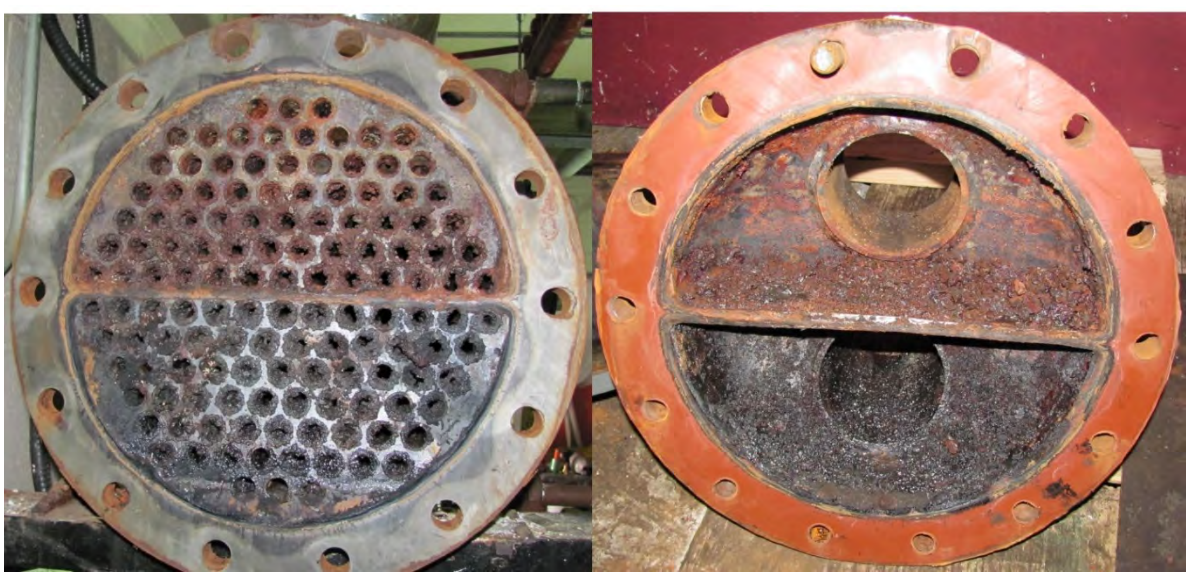

Figure 19: *The photograph on the left shows the inlet/outlet end of the tube sheet of the curling rink chiller. The photograph on the right shows the dome cover with gasket in place as intended.*

Figure 20: *The photograph on the left shows the return end of the tube sheet of the curling rink chiller with the gaskets intact. The photograph on the right shows the return end dome cover.*

In addition to the black liquid, two pieces of metal were found to be embedded at the inlet end of the brine tube sheet. (See Figure 21.) Laboratory testing determined that the metal parts were a piece of metal (labelled 28A) with the same chemical content consistent with ASTM A53 grade B pipe and a piece of malleable wire (labelled 28B) with the same metallurgical properties as MIG-type welding wire.

Figure 21: *Two metal pieces found at the inlet end of the curling rink brine tube sheet. (Source: Forensic Engineering Report from Acuren Group Inc. — Appendix C)*

Neither metal part could be attributed to a failed or broken component in the brine circulation system or the chillers. Further testing revealed that the shape of the parts prevented them from being ingested very far into the brine tubes and that they had not damaged the brine tubes. Subsequently, the presence of the metal parts in the inlet end of the curling rink brine tube sheet was determined to not be a contributing factor in the incident.

The exposed tube sheet ends were cleaned using soft cloths. No breach or evidence of a leak could be visually observed at the tube sheet ends. Examination of the tube interiors with a small-diameter video scope (borescope) proved to be inconclusive due to the buildup of black, oily liquid in the tubes. Pressure-leak tests conducted with 3 psi of nitrogen and acoustic monitors identified several potential leaks in the brine tubes, with the strongest indication being a leak in the third tube in the second row from the top of the curling rink chiller.

Further field testing on the curling rink chiller was halted. The brine circulation end plates and gaskets were reinstalled. The brine inlet and outlet pipes that had been previously severed were sealed. The compressor connections to the unit were severed and sealed. The entire chiller was filled with a 3 psi charge of nitrogen to prevent further corrosion before being shipped to the forensic testing laboratory for further examination.

Upon arrival at the laboratory, the curling rink chiller was found to still contain high levels of ammonia in the brine areas and ammonia pressure shell. The chiller was purged with inert argon gas and the curling rink chiller was disassembled for further examination.

At the laboratory, non-destructive testing was performed on the ammonia pressure shell for the chiller. The testing revealed that there was no significant thinning of the walls for the ammonia pressure shell.

The end plates were removed from both ends of the tube bundle. Leak tests using penetrating dye determined that no leaks were present where the tubes were mechanically joined to the tube sheet plates. The tube sheet plates were cross-sectioned at the mechanical rolled joints. No manufacturing error or leaks were detected at these locations. (See Figures 22 and 23.)

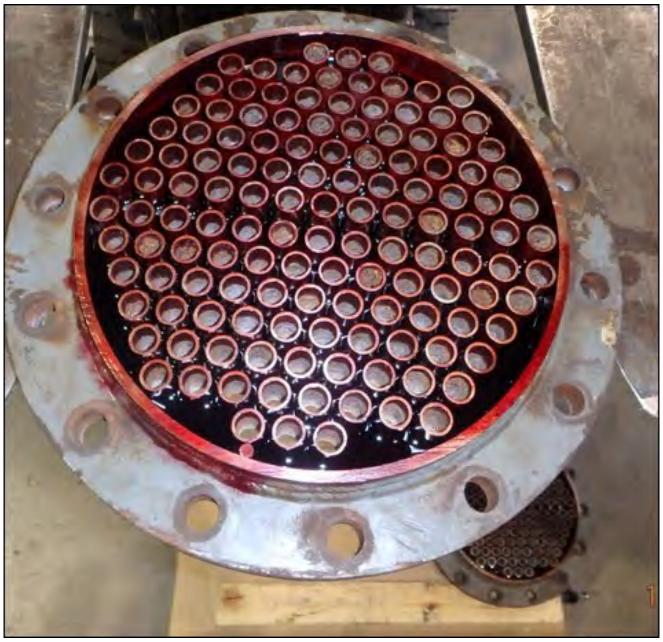

Figure 22: *The cross-sectioned tube sheet in the foreground; the second sheet is in the lower right corner of this photograph, with the ammonia pressure shell end facing up. A red penetrating dye bath has been added to test for permeation through the tube sheet. (Source: Forensic Engineering Report from Acuren Group Inc. — Appendix C)*

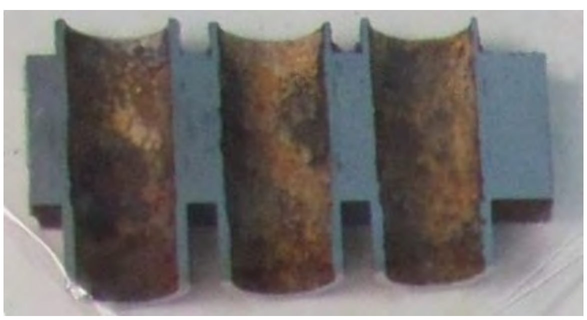

Figure 23: *Three brine tubes cross-sectioned at the tube plate. Examination showed good mechanical connection of the rolled tubes with no evidence of leaking.*

Sections of the ammonia pressure shell were removed at the inlet/outlet end of the curling rink chiller. A layer of fine white crystal growth was observed on top of the tube bundle at the brine return end and on the interior walls of the ammonia pressure shell. Chemical analysis determined that the substance was nearly pure calcium chloride crystal. The finding was unusual as the brine is not designed to enter the ammonia pressure shell under normal operating conditions.

Investigators observed unusual corrosion patterns that appeared to originate from the third tube of the second row. (See Figure 24.)

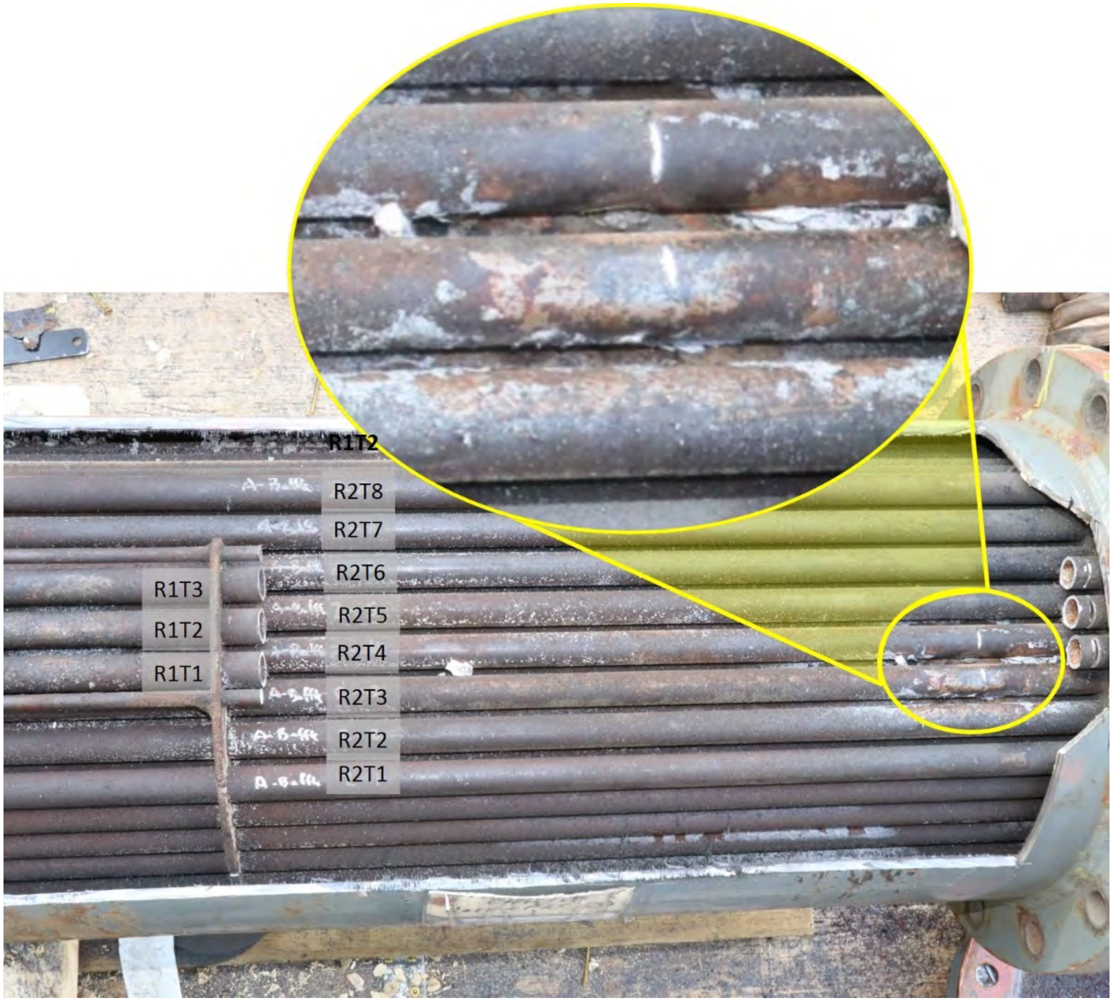

Figure 24: *Photograph with close-up showing radial patterns and corrosion in the second row of brine tubes at the outlet end of the curling rink chiller.*

Short sections were removed from the tube bundle for closer examination. Further examination confirmed that there was a breach in the brine tube located in row 2, tube 3 (R2T3). (See Figure 25.)

Continued examination of other tubes and the chiller at large did not identify any other breaches, leaks, or failures in either the brine or ammonia areas of the curling rink chiller.

Figure 25: *Photograph showing brine tube R2T3 after removal from the tube bundle. WorkSafeBC investigators observed a small hole in the tube (yellow arrow).*

Tube R2T3 was extensively examined. (See Appendix C: Forensic Engineering Report — Acuren Group Inc.) The breach was characterized by a series of corrosion holes comprising an oval-shaped area approximately 2.2 millimetres in length. (See Figure 26.) The entire volume of ammonia that led to the deaths of the three workers in this case can be attributed to the loss of containment of the ammonia through this relatively tiny hole.

Figure 26: *Close-up of the exterior of tube R2T3, showing the hole that allowed ammonia to enter the brine circulation system.*
(Source: Forensic Engineering Report from Acuren Group Inc. — Appendix C)

2.3 Progression of mechanical failures

The mechanical failures in the refrigeration system took place in two distinct stages. Stage 1 was the breach in the chiller tube, which allowed the ammonia to mix with the brine. Stage 2 was a loss of containment of the ammonia-brine mixture from the brine circulation system into the compressor room, where workers were performing maintenance on compressor 1.

The duration of time between the stage 1 mechanical failure and the stage 2 mechanical failure was at least 6 months and 4 days (186 days) — calculated from the first observation of ammonia in the brine by Rink Attendant 2 and Rink Attendant 3. The stage 1 mechanical failure may have occurred earlier but was not detected.

2.3.1 Process and effect of stage 1 mechanical failure

Analysis conducted at the forensic testing laboratory determined that the breach in tube R2T3 was orientated at the 4 o'clock position on the tube, and began on the brine side (inside) of the tube and progressed outward. (See Figure 27.)

Figure 27: *Close-up of the hole from the inside of brine tube R2T3. Scouring from the flow/jetting of material into the brine tube can be seen directly below the hole. Other pits have developed on both sides of the breach.*
(Source: Forensic Engineering Report from Acuren Group Inc. — Appendix C)

Prior to the creation of the breach, a series of small corrosion holes, or pits, had developed. The pits were of varying depths and had formed in a near-perfect straight line along the length of the tube. The holes were also arranged in groups, so that the line of corrosion presented a pattern similar to stitches made by a sewing machine, or a zipper. (See Figure 28.) This type of pitting is referred to as *preferential corrosion* in this report.

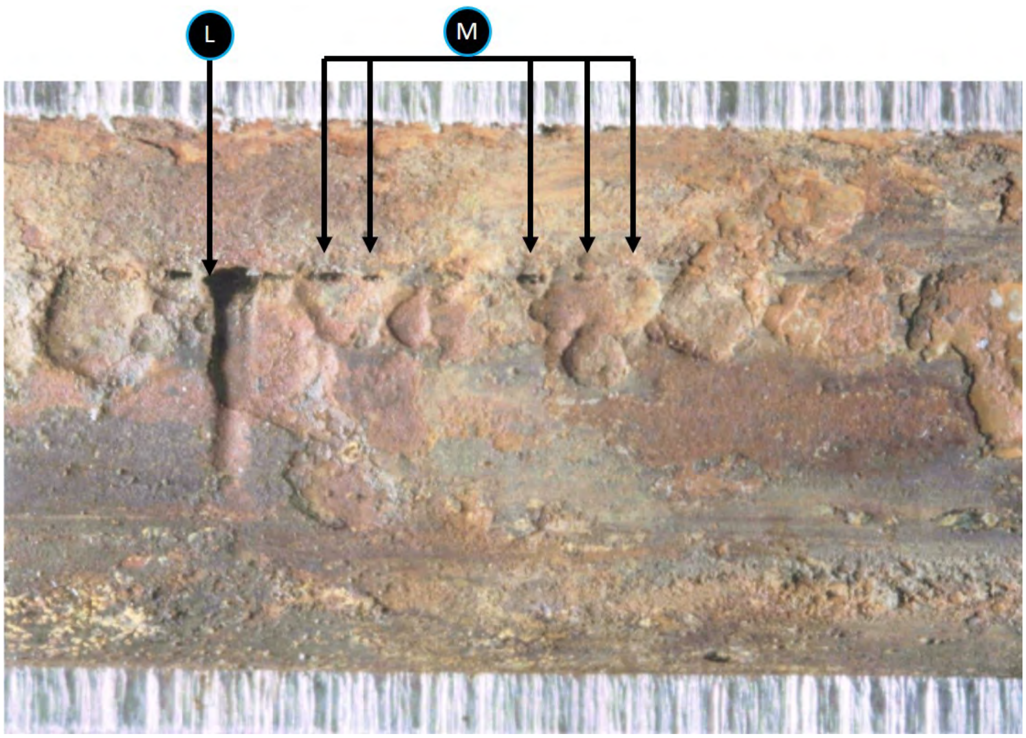

Figure 28: *Interior view of brine tube R2T3 after it was cut horizontally. The breach hole (L) is aligned horizontally with other pits that have not corroded all the way through the brine tube (M). (Source: Forensic Engineering Report from Acuren Group Inc. — Appendix C)*

The same effect was also observed in other tubes from the curling rink chiller. The line of pitting was not orientated in any specific direction relating to their installation position in the tube bundle (that is, top, bottom, left, or right). Instead, the pitting was observed to be aligned along the length of each tube, at the seam welding for the tubes. (See Figure 29.)

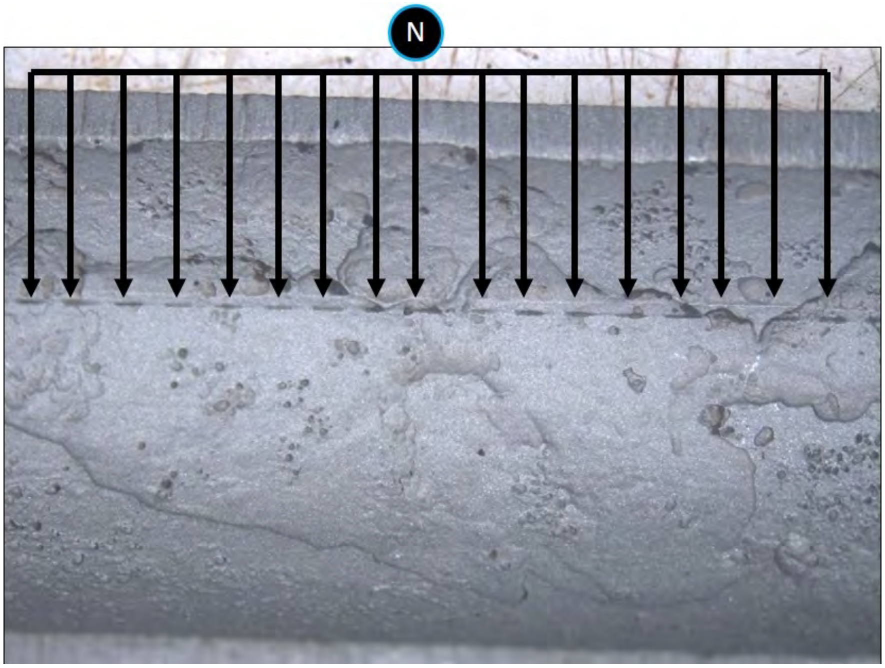

Figure 29: *Interior of a different brine tube (R4T1) after it was cut horizontally and cleaned. A distinctive line of corrosion pits can be seen along the length of the tube interior (N). (Source: Forensic Engineering Report from Acuren Group Inc. — Appendix C)*

The tubes were originally manufactured by rolling a flat sheet of steel into a tube shape and then welding the seam. The process used for welding the seam of these tubes was referred to as electric resistance welding (ERW). Since the time when the curling rink chiller was manufactured, there has been extensive metallurgical study and discussion on this type of manufacturing process. A typical shortfall of low-frequency ERW is a lack of fusion during the welding cycle that deposits iron oxide in regular intervals.

When the weld is exposed to chloride ions (from the brine), the ions will bond specifically to the iron oxide, causing corrosions pits in areas where the iron oxide is available. This process accounts for the preferential corrosion patterns observed in the chiller tubes and was the corrosion mechanism that ultimately led to the breach in brine tube R2T3.

The existence of a hole in the curling rink brine chiller tube allowed for the refrigerant and the heat exchange fluid to migrate in either direction as follows:

During operating conditions, the pressure differential between the heat exchange fluid and the ammonia liquid/gas could fluctuate depending on the individual system temperature and the turning on or off of components such as the brine pump and the gas compressors. As a result, the breach in tube R2T3 would allow ammonia to enter into the brine circulation system under some conditions, and in other operating conditions, brine would be able to enter the ammonia system. This process is referred to as *flow reversal* in this report.

The concept of flow reversal accounts for the presence of large amounts of calcium chloride crystals observed after the incident throughout the ammonia circulation system, specifically in the gas compressors and the ammonia pressure shell of the chiller. The presence of high ammonia readings in the brine sample are also accounted for due to the flow reversal mechanism.

From analysis of the breach in tube R2T3, WorkSafeBC investigators determined that the stage 1 mechanical failure was neither sudden nor catastrophic in nature. The corrosion pits that led to the breach formed over an extended period of time and were likely promoted by the seasonal shutdown and start-up cycle for the equipment. The extensive brine intrusion into the ammonia circulation system indicates a sustained problem that was given enough time to develop into widespread system contamination.

Warning signs were present that a containment failure of the ammonia had occurred in the curling rink chiller. The anecdotal observations reported by Rink Attendant 2 and Rink Attendant 3 approximately six months prior to the incident and the second confirmation and warning from the independent laboratory in August 2017 provide clear evidence that the ammonia circulation system at the Fernie Memorial Arena was significantly compromised.

2.3.2 Effects of stage 2 mechanical failure

WorkSafeBC investigators determined that the brine contamination into the ammonia system likely had an impact on the components of the system as exhibited by system stress items observed by workers: fouled compressor oil, poor function of the ammonia liquid feed valves, and automatic system shutdowns. Although the presence of brine made management of the ammonia system challenging and would have likely led to continued systemic problems and potential future breakdowns, the intrusion of the brine into the ammonia circulation system was not a direct contributing factor in this incident.

The brine circulation system was not designed to handle any ammonia; the intended level of ammonia in the brine circulation system for a flooded ammonia chiller is 0 ppm. However, due to the high affinity that ammonia has for water, it is recognized in the refrigeration industry that trace amounts of ammonia can be present in the brine. A detected concentration of 50 ppm by volume or less is generally accepted as non-problematic.

When the curling rink brine loop was operating, the breach of tube R2T3 would have allowed the refrigerant to be injected into the flow of the brine stream at the point where the brine was exiting the outlet port of the curling rink chiller. In consideration of the turbulent environment produced by the boiling ammonia during the heat exchange process, WorkSafeBC investigators determined that it was possible for ammonia to have been injected into the brine system in both gaseous and liquid states.

When ammonia contacts the water in the calcium chloride brine, a chemical reaction can take place. The reaction results in a new molecule, ammonium hydroxide. During the creation of the

ammonium hydroxide, energy is given off in the form of heat, which raises the temperature of the resultant mixture.[3]

This reaction is susceptible to time, volume, pressure, and temperature, which will all affect how much ammonia is absorbed into the brine. If the conditions are not perfect, it is possible for a mixture of brine, ammonium hydroxide, and free ammonia in liquid and gaseous states to all be present in the reaction container at the same time. In this case, the unintended reaction container was the curling brine loop piping.

As the ammonia contaminant circulated around the brine loop, any gaseous products of the reaction would have been expelled as intended through the brine expansion tank. If ammonia liquid was contained in the piping, the pressure exerted on the liquid would have reduced the higher it rose to the surface in the brine expansion tank. In essence, the gaseous and free ammonia liquid would have boiled out of the contaminated mixture.

This phenomenon accounts for the shaking and spilling observed by the [redacted] and firefighters when they entered the compressor room prior to the incident. As the brine expansion tank was not sealed, this process would also account for the high ammonia alarms triggered by the automatic ammonia gas detector system in the compressor room, which first alerted the workplace parties that there was an ammonia problem in the compressor room.

The breach of tube R2T3 would have allowed the refrigerant to be injected into the flow of the brine stream at the point where the brine was exiting the outlet port of the curling rink chiller. In consideration of the turbulent environment produced by the boiling ammonia during the heat exchange process, WorkSafeBC investigators determined that it was possible for ammonia to have been injected into the brine system in both gaseous and liquid states.

The curling rink brine loop is essentially a closed system with the exception of the air-bleed hole in the brine expansion tank. As a closed system, the heat exchange liquid moves around the system in a loop, but brine is neither added nor subtracted in this process. As such, the pressure forces exerted by the pumped liquid on the pipes and fixtures in the system remain somewhat constant.

Even though the refrigeration system was turned off, the ammonia was not removed from the curling rink chiller. Therefore, for a time after the shutdown, the refrigerant in the chiller was at a higher relative pressure than the liquid in the curling rink brine loop, so the ammonia continued to be injected into the brine circulation system at the breach of tube R2T3. The continuous influx of ammonia caused several imbalances to occur in the closed system:

[3] Kenneth A. Kobe and Ted S. Markov, *The Preparation of Ammonium Hydroxide for Laboratory Use*, J. Chem. Educ., 1941, 18(1), p. 29.

- By adding ammonia, the volume of material rose, which induced a system-wide pressure increase.
- The reaction that produces ammonium hydroxide gave off heat, which also created a system-wide pressure increase.
- When the equipment was shut down, the refrigeration cooling ceased, meaning that from the time the equipment was shut down, the temperature of the brine, ammonia, and all components of the system such as pipes and valves began to rise.
- As ammonia has a strong tendency to change state in relation to temperature increase, the warming process also caused a pressure increase in the closed system.

Unlike ammonia and water vapour, liquids — in this case, the aqueous brine mixture — are in general relatively incompressible. Subsequently, a closed system can only absorb so much additional pressure until the system fails at the weakest point. As discussed previously, under ideal conditions, the unrestrained horizontal coupling on the curling rink brine outlet pipe could perhaps withstand a maximum pressure increase of 30 psi before separation of the joint began to occur. Even if this amount were tripled, to take into account the weight of the pipe, corrosion, or any other unknown factor, the pressure required to separate the pipe remains substantially less than the factory-set opening pressure for the pressure-relief valves.

WorkSafeBC investigators concluded that the stage 2 mechanical failure occurred as a direct result of the mixing of ammonia and brine, creating a pressure rise in the closed system. This pressure rise ultimately overcame the holding ability of the HC, causing it to release the pressurized, toxic ammonia-brine mixture without warning. (See Figure 30.)

WorkSafeBC investigators also determined other components in the curling rink brine circulation system (for example, the brine filter connections and housing) could have failed at pressures below the opening pressure for the pressure-relief valves on the curling rink chiller. Since the system was not intended to handle the pressures it was exposed to as a result of the leaking ammonia, it can be stated that the pipe separation at the HC connection represented only the weakest link in the system's ability to withstand pressure in this case. If the pipe at the HC connection had held in place, it is possible that the stage 2 mechanical failure could have taken place in another part of the curling rink brine circulation system.

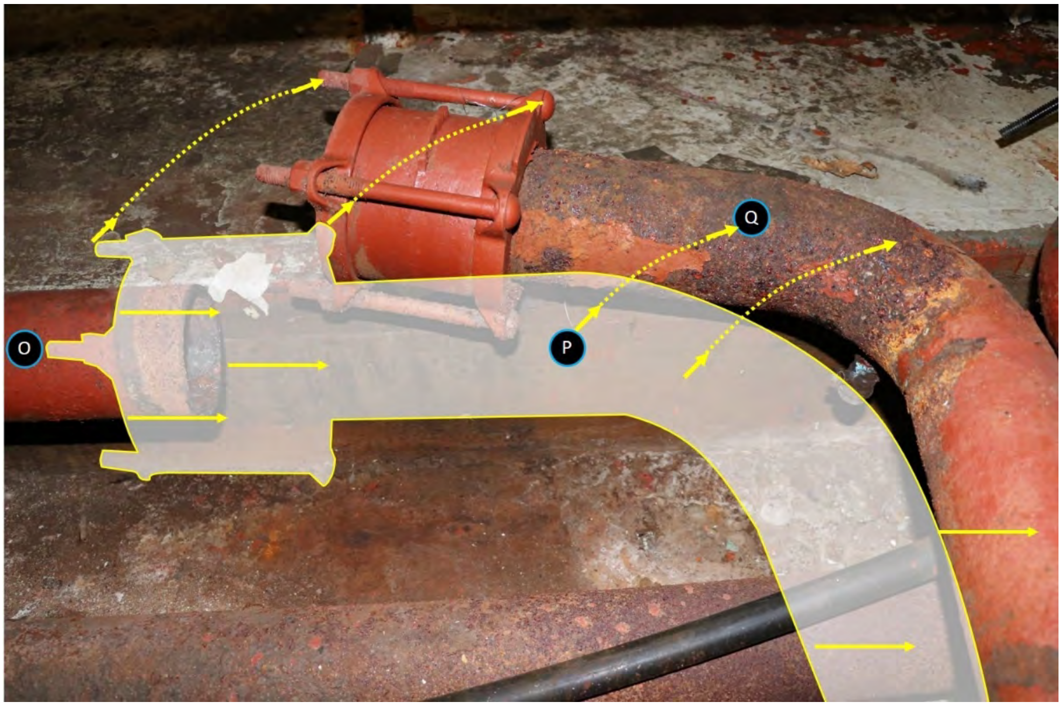

Figure 30: *The separated HC fitting on the curling rink brine outlet pipe. The pipe separated because the process of ammonia leaking into the brine developed more pressure than the piping system was able to contain. The pipe section on the left side of the photograph (O) was embedded in the concrete slab and remained stationary. The HC and attached pipe section (P) were unrestrained. When the pressure increased, the HC and pipe section were able to move backward and rotate out of position substantially (Q), as observed by WorkSafeBC investigators after the event.*

2.3.3 Effects of mechanical failures on ancillary systems

The compressor room had a ventilation system that was always running and pulled air to the roof through a mounted extraction fan. The ammonia gas detector system was connected to an emergency ventilation system that was programmed to come on when a specific ammonia level was detected in the room.

The emergency ventilation system was not intended for the purpose of providing respirable air to workers in the compressor room. Instead, the emergency ventilation was designed to ensure that in the event of an ammonia leak, the mixture of ammonia and air would stay below the lower explosive limit and therefore prevent conditions that could cause an explosion to occur. That is to say, the intended purpose of the emergency venting was to protect the compressor room and the facility, not necessarily persons inside the compressor room.

Operation of the ammonia gas detector system was dependent on a perishable ammonia sensor mounted on the ceiling on the north side of the compressor room. The sensor had been installed

and calibrated on October 3, 2016, about a year prior to the incident. Due to the sustained high-ammonia reading and humidity in the compressor room after the incident, there existed the possibility that the sensor life might have been reduced or fully depleted, and therefore was unreliable for function testing the entire system after the incident.

As such, the system components were tested for function using a milliamp-ranged signal generator to simulate input readings from the ammonia gas detector. The following observations were recorded:

- At 09.49 milliamps (35 ppm) of ammonia, the low-level system alarm activated. The amber warning light system throughout the facility activated. All lights in the facility were operating.
- At 19.15 milliamps (96 ppm) of ammonia, the audible alarm at the detector activated and sounded, and the emergency exhaust fan activated.

The louvres and venting for both fan systems were found to be operating as intended. It was observed that the belt on the pulley system that ran the emergency ventilation fan was severely damaged. It should be noted that the RPM (revolutions per minute) of the large exhaust fan was not smooth and the speed was oscillating due to the worn fan belt. As such, the measurements obtained with direct-reading equipment, as listed in the bullets above, should be viewed as approximate.

When the emergency exhaust fan was operating, it could be stopped by pressing and holding an operator stop button, but if the alarm reading was still active, the fan would turn on again when the button was released.

The total air flow when both fans were running and vents were opened was measured to be 2181 cubic feet per minute. The large exhaust fan was determined to produce 1287 cubic feet per minute of airflow.

It was observed that the HVAC (heating, ventilation, and air conditioning) system for the facility was located beside the compressor room. A series of smoke tests were conducted to demonstrate the flow of vapours out of the compressor room when all of the room ventilation was running. The testing indicated that when ammonia gas was vented out of the room to the roof area, it was possible for the ammonia to be recirculated into the makeup air system for the facility's HVAC system and then dispersed through floor ducting to various areas of Fernie Memorial Arena.

The emergency stop buttons would have turned off the HVAC system; however, these devices were not used to shut the refrigeration system down. Instead, local controls were used to shut down the equipment one component at a time. The emergency stop button located outside of the compressor room was pressed by emergency responders after the stage 2 mechanical failure had occurred.

The alarm monitoring company records show that from the time of the initial alarm till the time the [redacted] advised the alarm monitoring company not to dispatch a response for further alarms, the automatic monitoring equipment was consistently giving indications of high ammonia readings in the compressor room. WorkSafeBC investigators determined that the automatic ammonia gas detector system and emergency ventilation were functioning as intended prior to the incident.

2.4 Significant events

WorkSafeBC investigators examined the sequence of events and identified five distinct events that occurred prior to the stage 2 mechanical failure. These actions and events significantly impacted the health and safety of the workers involved, and combined together to produce the fatal outcome in this case.

2.4.1 Compromised chiller was put into service

There was a six-month period prior to the incident when the curling rink chiller was not operational but was suspected or known to be compromised and leaking, after the spring shut down. No repairs, assessments, inspections, or contingency plans to address the problem of leaking ammonia were conducted prior to fall start-up.

CIMCO did not recommend against restarting the compromised curling rink chiller. Correspondence records of the conversation about the high-ammonia readings indicate that the recommendation from the CIMCO [redacted] was instead to monitor the levels further. Ultimately, the curling rink portion of the refrigeration system was put back into operation even though it was known that containment of the ammonia had been lost and the heat exchange fluid was highly contaminated with ammonia, a chemical the brine system was never designed to handle. The Refrigeration Supervisor stated CIMCO representatives were unaware that Fernie workers had restarted the curling rink part of the refrigeration system until the first alarms occurred on the day of the incident.

The start-up of the curling rink portion of the refrigeration system in a failure mode represented a dangerous operating condition in the workplace that was not identified or addressed by any workplace party for the duration of the incident.

2.4.2 Abrupt shutdown

The refrigeration system was shut down abruptly after it had been in operation for over 21 hours. The emergency shutdown due to multiple alarms from an apparent refrigerant leak can be characterized as an upset condition.

Under normal conditions, shutdown of a flooded ammonia chiller would include *pumping down* the chiller, which refers to a process of moving all or most of the ammonia liquid from the chiller pressure shell to the high-pressure receiver for storage. (See Appendix E: As-found Valve Positions Drawings.)

This pumping down process was not completed when the refrigeration system was shut down. A possible explanation of this may be that the oil supply for the two ammonia gas compressors had already become contaminated with enough brine to prevent them from functioning. No plan was developed to effectively to deal with the ammonia liquid that remained in the chiller, other than to close the ammonia valves leading into and coming out of the curling rink chiller. As a result, a charge of ammonia liquid remained within the pressure shell of the compromised curling rink chiller after the shutdown occurred. This ammonia charge continued to leak into the brine after the chiller was closed off from the rest of the system.

Calculations were completed by refrigeration specialists using normal ammonia and brine volumes after the incident. These calculations determined that if the brine system had remained circulating, there would have been a sufficient volume of water in the brine to absorb the entire ammonia charge from the leaking chiller. Had the brine system remained flowing, the overpressure situation that took place with the HC fitting would not have occurred in the same way, and potentially not at all. (See Appendix D: Refrigeration Subject Matter Expert Technical Report — Strong Refrigeration Consultants Inc.)

WorkSafeBC investigators determined that several other options were available for the workers addressing the ammonia problem. Options included pumping down the chiller so the ammonia was stored in the receiver, or a controlled, intentional release of ammonia to atmosphere through the emergency vent line. These options were not exercised. An intentional release of ammonia to atmosphere ultimately did occur when the system was opened by emergency responders.

2.4.3 Valving in the refrigeration system

When emergency responders first entered the compressor room after the initial alarm call was made around 04:00 hours, they observed that the brine expansion tanks were shaking and that brine was sloshing out. The [redacted] addressed this issue by closing the valves associated with the curling rink brine expansion tank. Afterward, he told the firefighters the system was under control and there was nothing more to worry about. He closed a number of other refrigeration system valves, which included isolating the ammonia pressure shell on the curling rink chiller. [redacted] Isolating parts of a system this way is referred to as *valving in*.

The shaking of the brine expansion tanks was the result of pressure being relieved from the closed system containing the brine and was an indicator that either ammonia liquid was boiling to gas and/or the reaction of the ammonia with water in the brine was developing unwanted pressure in the brine piping system.

When the flow lines to the curling rink brine expansion tank were effectively closed, flow was prevented and any pressure relief afforded through this pathway ceased. Instead, pressure began to build up inside the brine circulation system. Valving in the system trapped the volatile, ammonia-brine mixture in the piping between valves within the refrigeration system. This action

exacerbated the hazardous condition developed from the start-up of the compromised chiller and created the new hazard of unexpected sudden gas release.

Due to unknown variables associated with mixing volumes, system pressures, temperature, and time, it was not possible for WorkSafeBC investigators and subject matter experts to calculate how much pressure could have built up in the brine system after it was shut down. As such, the amount of pressure relief to the closed brine system that would have been afforded by the open 1-inch-diameter pipe on the brine expansion tank cannot be exactly determined. Therefore, it is possible that had the brine expansion tank valve remained open, the stage 2 mechanical failure might still have occurred.

2.4.4 Proceeding with restart maintenance

When the decision was made to do maintenance work on the two gas compressors, the ammonia containment in the curling rink chiller was already known to be compromised and the refrigeration system was in an upset condition.

The focus on changing out the oil in the gas compressors (in order to put the refrigeration system back into operation as soon as possible) diverted resources and attention away from the pressing issues of lost ammonia containment and trapped or rising pressure within the rest of the system. With the expertise available at the time, a plan to identify and mitigate these other issues could have been formulated and acted upon with no impact on the status of the gas compressors.

2.4.5 Removal of safety support systems

The emergency response to the initial ammonia alarms brought considerable resources in the form of trained, equipped, rescue personnel to the compressor room location. The firefighters who responded were familiar with the hazard of ammonia in the compressor room and had an ample supply of SCBAs, gas detectors, rescue equipment, and centralized communication at their disposal. The responders also had specialized knowledge for dealing with medical emergencies, evacuation, decontamination, and public safety.

After the refrigeration system had been shut down and valved in, the emergency responders were told by the [redacted] to leave the location, which they did. As a result, there was no longer any watch personnel, a rescue team, first aid, or outside communication available to the workers who remained to manage the ammonia leak in the compressor room.

In addition, the workers who remained no longer had access to SCBAs or air monitoring equipment. During an examination of the facility after the incident, a partially assembled personal gas monitor for ammonia was found in the rink attendants' office. No monitors were observed in the compressor room or on the clothing of the fatally injured workers. The [redacted] may have been wearing a half-mask air-purifying respirator, which would not have been adequate protection for the level of ammonia exposure that occurred when the HC failed.

Finally, the automatic monitoring and offsite alarm monitoring were silenced, so that audible alarms and emergency dispatch remained unavailable until several hours after the incident occurred.

Although the presence of any of these safety resources would not have prevented the incident from occurring, the potential that exposure levels to workers could have been reduced, and that detection and extraction times could have been dramatically shortened, must be considered as significant factors in this case. There was no secondary oversight or assessment in place to assist workers when the work on compressor 1 commenced. When the stage 2 mechanical failure occurred, no warning was provided to the workplace or community that a major release had occurred with the refrigeration system. Ultimately, the seriousness of the event was discovered instead by chance by the Electrician, who was not part of a trained ammonia rescue team and who, in the process of trying to rescue the fallen workers, was placed at high risk of exposure himself.

In consideration of the five subsections listed above, it can be stated that the response to the upset condition by the workplace parties from Fernie and CIMCO was unplanned and conducted in an uncoordinated manner in terms of workplace health and safety. Operation planning centred on minimizing downtime and was focused toward ensuring the facility remained accessible to the community user groups. As such, when alarms from escaping ammonia made it impossible to operate the leaking curling rink portion of the refrigeration system any longer, the response of the working group at Fernie Memorial Arena was to get the refrigeration system up and running as soon as possible so the impact to operations in the hockey rink would be minimized.

2.5 Health and safety

Fernie and CIMCO had occupational health and safety programs in place for protecting the health and safety of workers. The five critical events listed in section 2.4 above should have been prevented from occurring and/or continuing to develop, through a comprehensive hazard recognition, assessment, mitigation, and planning process.

Key elements of an effective occupational health and safety system are:

- Effective auditing and review of the safety system to ensure that it is being uses as intended in the workplace
- Access to and effective use of safety related information provided in the employers' program, and developed from workplace inspections, investigations, and observations of the workplace methods and practices.

WorkSafeBC investigators analysed the health and safety programs that were being used by Fernie and CIMCO at the time of the incident and determined key elements of both systems were either absent or ineffectively utilized when addressing the health and safety issues associated with the compressor room and the problem of the leaking chiller.

2.5.1 City of Fernie

Fernie had a written health and safety program that included safe work procedures and training requirements specific to the compressor room and refrigeration system. As well, Fernie had a joint health and safety committee (JHSC) as required by the Regulation. The investigation identified two other committees that also discussed the operation and maintenance of the Fernie Memorial Arena and specifically the refrigeration system: the Leisure Services Advisory Board (LSAB) and the City Council. There is evidence to show that important information relating to workplace safety was not forwarded for follow-up, was not shared, or was not otherwise considered between the three committees.

In review of documents obtained during the investigation, WorkSafeBC investigators identified key health and safety items related to the Fernie Memorial Arena that were not included in the JHSC discussions both before and after the ammonia was known to have breached containment in the curling rink chiller:

- Meeting minutes from the City Council on February 16, 2016, state: "The arena has some serious issues due to lack of maintenance with the ice plant. For the past 4/5 years there has not been proper maintenance done. At this time it is on life support to keep it alive until the end of the season."
- Meeting minutes from a September 7, 2016, meeting of the LSAB state: "The refrigeration plant had major repairs and the chiller will be repaired in 2017. Leisure Services feels that the building can be kept running for another 20 years."

The minutes from the City Council and LSAB meetings indicate that there were concerns and knowledge relating to the refrigeration system far in advance of the incident that occurred. There should have been coordination between the two committees and input from the JHSC to ensure that given this fact, an assessment of potential impacts and risks to workers and other users of the facility was conducted by a qualified health and safety professional and refrigeration specialist or specialists. Safety protocols could then have been put in place to ensure that continued operation of the refrigeration system would not compromise safety.

In the LSAB meeting on October 4, 2017, after the ammonia leak into the brine was confirmed, an LSAB representative stated, "getting a chiller is a priority in 2018." No discussion or contingency plan was developed in light of the fact that the curling rink chiller was in failure mode before the curling rink season commenced.

Overall, WorkSafeBC investigators determined that the following facts, which directly affected the health and safety of front-line workers, were not universally understood by any of the three committees:

- Two workers reported to the [redacted] in April 2017 that they detected a smell of ammonia in the brine system, and noted the observation in the maintenance logbook.

- The independent laboratory warned about the refrigerant leak and high levels of ammonia in the brine in May and August 2017.

Records provided by Fernie to WorkSafeBC investigators show that the JHSC met on nine occasions in 2017, with the last meeting occurring on August 17, 2017. None of the records mention the developing issue of ammonia leaking into the brine system. The report by Rink Attendant 2 and Rink Attendant 3 about ammonia detected during filter changes on April 13, 2017, was not included in discussions at the April 19, 2017, meeting or any subsequent meeting. The same was true of the brine reports received from the independent laboratory.

Although the Leisure Services workers monitored the compressor room for machine readings, such as oil levels, operating pressures, and temperatures on a regular basis, workplace safety inspections were only done sporadically and not in accordance with section 130 of the *Workers Compensation Act* and section 3 of the Regulation.

WorkSafeBC investigators analyzed the inspection records provided by Fernie. There are two types of forms; the first is titled "Worksite Safety Inspection Form." A total of 11 workplace inspections were documented on these forms by the Leisure Services group at Fernie Memorial Arena between January 15, 2015, and September 14, 2017. No inspection records were provided for 2013 or 2014; however, a tracking list was provided shows some inspections were done in those years as well. The records show on average, the workplace safety inspections were conducted 4.5 times a year from 2013 to 2017. Of the 11 inspections, 8 were conducted independently by the [redacted]; the remaining 3 inspections were conducted by a worker representative without accompaniment by a management representative.

The second inspection form is titled "Facility Inspection Report (W8)." These forms are general facility inspections that document repairs or issues that inspectors thought needed to be addressed. Although not specifically tailored to health and safety, these forms do include an area for the "refrigeration room" (*compressor room* in this report). Twelve completed inspection forms were provided to WorkSafeBC investigators. There were 11 inspections for 2016 and 1 for 2017. The [redacted] did 3 inspections, and the remaining 9 were done by rink attendants. Every form that was provided lists "Curling brine line corrosion," and some amended the statement to state that it was "painted in July 2016."

These workplace inspections did not identify other issues in the compressor room or with the refrigeration system. This fact contrasted with observations and notes entered in the maintenance logbook. Specifically, logbook entries or conditions known to have been present are as follows:

- Logbook entry on October 11, 2016: "Curling Brine lines seem to leak, brine tank lower than normal." Neither type of inspection form was completed in October 2016.
- The ammonia liquid high-level shutdown switches were intentionally disabled, as observed by CIMCO on August 11, 2016, and in the logbook on February 23, 2017.
- Ammonia alarms and apparent ammonia sensor malfunction in December 2015.

- Reports by rink attendants of ammonia in the brine and subsequent follow-up activities as previously discussed in this report.

The employer received information from the JHSC that the inspections and incident reports were not being consistently completed but did not implement any plans to address the issue. On July 20, 2017, the meeting minutes indicate that the committee had used the WorkSafeBC self-evaluation tool six weeks earlier. The results were documented as follows: “The evaluation uncovered that the committee needs to do a better job of performing workplace inspections and in following up on recommendations that are made after an incident or investigation.”

WorkSafeBC investigators concluded the workplace safety inspections conducted at the Fernie Memorial Arena were ineffective for detecting and correcting safety issues that contributed to the development of unsafe working conditions. This fact became acute on the day before the incident as none of the rink attendants were informed by their employer that ammonia containment had been lost in the chiller and that the brine was highly contaminated with ammonia. This safety-significant information should have been brought forward and discussed with the JHSC and the LSAB so their recommendation and decisions could be based on the critical information available at the time, regarding worker safety. Having not been included, these groups were instead operating with incomplete information. Collectively, the operational components of Fernie’s management system should have communicated important facts, assessed the hazards of operating the refrigeration plant, and developed a contingency plan to protect the health and safety of workers.

WorkSafeBC investigators also conducted a review of Fernie’s written policies and procedures related to the refrigeration system. These documents were, overall, general in natural, over 20 years old in some cases, and were last reviewed approximately 5 years prior to the incident. No procedures had been drafted to address the risks to workers when working with or around the refrigeration system in an upset condition after the leak was confirmed in August 2017. There was an exposure control plan for workers who may be exposed to ammonia, but it was not clear that a risk assessment as prescribed in the Regulation — Toxic Process Gases — had been incorporated into the policies and procedures. The exposure control plan did not address all requirements in the Regulation.

Despite the general nature and age of Fernie’s written procedures, WorkSafeBC investigators determined there was enough prescriptive information included in the written materials to prevent the fatal outcome in this case — if the procedures had been followed. Below is a list of Fernie’s safe work procedures that WorkSafeBC investigators identified as having not been followed by senior managers and decision makers in this case.

- The document titled “Arena Emergency & Evacuation Procedure” prescribes that building security must ensure that no person re-enters the building. This did not occur. After the first ammonia alarms at 04:00 hours, there were no provisions in place to prevent people from approaching the area where the ammonia had been released. [redacted] was able to enter the facility twice, and the Curling Club Member accompanied her once without

knowing that a situation was under way. When the stage 2 mechanical failure occurred, there were no barriers or watch personnel in place to prevent members of the public or other workers from additional exposure.

- The safe work procedure for maintenance work in the compressor room prescribes the use of personal protective equipment for respiratory protection and specifies that such equipment is a full-facepiece respirator fitted with air-purifying cartridges. While maintenance work was being performed on compressor 1 after the firefighters had departed, none of the fatally injured workers was wearing or had such a respirator, and no such respirators were discovered at the ready at the incident scene. The [redacted] was observed to have had a half-facepiece respirator at the ready. This type of mask does not protect the eyes, has a reduced protection factor, and otherwise is not the same level of personal protective equipment indicated in the safe work procedure. It should be noted that Fernie workers were never issued full-facepiece respirators, and it was therefore not possible to comply with all of the safe work procedures.

- A Fernie document titled “Ammonia Leak Emergency Procedure” states that after an ammonia leak has been detected and responded to, the “department head” is required to conduct a formal incident investigation and contact specific authorities, including WorkSafeBC. This was not done. After the initial emergency response to the ammonia alarm determined that there were no injuries or persons who required care, there should have been a cessation of any further activity involving the compressor room so that available information could be reviewed and a coordinated response plan developed. A pause in the sequence of events at this stage could have allowed for critical input from refrigeration, health and safety, and emergency management specialists in a meaningful way. Failure to adopt a standard practice of incident investigation previously left the managers and decision makers without situational experience and familiarity with important procedures when faced with the ammonia alarm problem. The focus on returning the plant to service in order to minimize the impact to other facility operations minimized the significance of the ammonia containment leak and set into motion a series of actions that would ultimately end in tragedy.

- The written emergency response plans for addressing ammonia leaks and evacuation at Fernie Memorial Arena had not been reviewed since October 2012. There had not been an evacuation drill to test the procedures since October 2014, [redacted]

WorkSafeBC investigators determined, after examining Fernie’s occupational health and safety system, that poor communication and inconsistent attention to internal auditing, inspections, incident investigation, and emergency practice drills allowed for the development of hazardous workplace conditions in the Leisure Services Department, specifically in the compressor room at Fernie Memorial Arena in the months and hours prior to the incident. A lack of adherence to the employer’s own safe work procedures at the senior management level removed the benefit of interdepartmental oversight and resources, which resulted in a failure of the system to protect the health and safety of workers as intended.

2.5.2 Toromont Industries Ltd. (CIMCO Refrigeration)

CIMCO provided a copy of their written occupational health and safety program and related material, which comprised 18 separate sections totalling 1024 pages. For the purposes of this report, the associated program elements discussed below are categorized as proactive measures and emergency measures.

WorkSafeBC investigators determined in the documents provided, there is no evidence of a completed risk assessment, job hazard analysis, or stand-alone safe work procedure to direct workers on how to safely proceed with refrigeration system maintenance when faced with a compromised flooded ammonia chiller, as was the case when the Refrigeration Mechanic was dispatched.

Within the proactive measures of the health and safety program, CIMCO included a substantive document titled “Working with Ammonia.” The Refrigeration Mechanic and the Refrigeration Supervisor had both received training in the document, which provides a comprehensive overview of the hazards of ammonia when used in a refrigeration system. In section 6.1.1, under the heading “General Precautions,” the document warns:

> Liquid ammonia has a high coefficient of thermal expansion. Care should be taken to ensure that liquid ammonia is not trapped in pipelines or fittings between shut-off devices. A rise in ambient temperature may be sufficient to expand trapped liquid, generate excess pressure and rupture components.

This scenario closely relates to the circumstance involved in the pipe separation when the stage 2 mechanical failure occurred. Although the Refrigeration Supervisor and the Refrigeration Mechanic were aware the brine tanks had been shaking and splashing over, that ammonia-contaminated brine had been valved in, and refrigerant was leaking from the ammonia pressure shell from an unknown source at an unknown volume, they did not recognize the potential of component failure as a high-risk hazard and did not include this possibility in the decision-making process.

Under the heading “Hazard assessment, control, and reporting program,” CIMCO provided a series of assessment tools to be used at the field level to assess and control hazards encountered by workers during service calls to customer workplaces. These tools include:

- Customer Service Reports
- Job Hazard Assessment
- Unique Hazard Report
- Specific or Custom Procedure Development

WorkSafeBC investigators did not find evidence to show any of these assessment tools were used prior to the Refrigeration Mechanic’s arrival at the Fernie Memorial Arena or during his time there. During interviews with WorkSafeBC investigators after the incident, the Refrigeration Supervisor did not state that he discussed the use of these items on the day of the

incident with the Refrigeration Mechanic, but explained they were normally completed by the Refrigeration Mechanic and generally reviewed by the Refrigeration Supervisor after each deployment. The records provided by CIMCO and Fernie corroborate the Refrigeration Supervisor's statement and also demonstrate the Refrigeration Mechanic had completed the forms and documented key safety practices during his previous service calls to the compressor room at the Fernie Memorial Arena. Subsequently, it can be hypothesized that any fully or partially completed document(s) were lost as a result of the violent sudden release that occurred during the stage 2 mechanical failure or were not otherwise available to WorkSafeBC investigators after the incident.

WorkSafeBC investigators received and reviewed blank example forms from CIMCO to determine how they would assist in identifying and controlling the hazards associated with the compromised refrigeration system in the compressor room. Even if the Refrigeration Mechanic possessed the knowledge gained after the incident occurred, it would have been extremely challenging for him to effectively assess and implement hazard controls. These controls might have identified and/or mitigated the impact of the stage 2 mechanical failure of the refrigerant containment in the compressor room with the field-level tools provided in the CIMCO safety program.

WorkSafeBC investigators determined the absence of an adequate safe work procedure and risk assessment to address a predicted and known failure mode of the flooded ammonia chiller critically undermined the effectiveness of the employer's proactive health and safety system in this case.

Emergency measures in the CIMCO health and safety program are outlined in another substantive document titled "Ammonia Emergency Response Procedures" (referred to here as the procedure). The procedure provides specific guidance on how to respond to a report of an unexpected ammonia release and includes specific steps for assessing the type of response, personnel complement, training, hazard mitigation, and other safety measures required in these situations. The procedure outlines protocols for large and small ammonia releases both inside and outside of compressor rooms, and details the qualifications and response parameters of five separate levels of responder competency. The procedure also provides specific instruction for tying into or pumping out an ammonia system and includes the following:

> Always reduce the system and equipment internal pressure to 0 psig [gauge pressure measured relative to ambient atmospheric pressure] before the tie-in process is started ….
>
> Ensure that no liquid is trapped between the shut off valves and/or solenoid valves.

Section 5.6 of the procedure states:

> If an accidental ammonia release has occurred or the ammonia concentration is above the IDLH [immediately dangerous to life and health], there is a potential for danger. The ARTech [refrigeration technician] should not attempt entry into such a hot zone without three

additional Emergency Response Technicians and must follow this emergency response procedure.

The term *IDLH* — immediately dangerous to life and health — refers to worker exposure to a concentration of a known airborne contaminant. In the case of ammonia, the IDLH is 300 ppm. This concentration was in fact recorded by the firefighters who responded to the initial unexpected ammonia release that occurred at the arena, and as such both of the conditions were met for initiating the procedure as outlined above.

The procedure was not implemented, and the guidance and direction provided in the procedure were not discussed between the Refrigeration Supervisor and the Refrigeration Mechanic before or after the direction was given to attend the location of the unexpected ammonia release at the Fernie Memorial Arena.

WorkSafeBC investigators concluded the decision of not implementing and/or following the guidance provided in the CIMCO ammonia emergency response procedure was a significant factor in this workplace incident.

Upon review of the CIMCO health and safety program, WorkSafeBC investigators determined the Refrigeration Mechanic was dispatched to work on a refrigeration system that was known to be in an upset condition. The dispatch was made in the absence of a proactive safe work procedure developed from a comprehensive hazard assessment to deal with a system in such a condition. The hazard recognition and assessment tools available to the dispatched worker and supervisor did not combine in a meaningful way to effectively control worker exposure to the developing hazards in the compressor room. The failure to consider the unexpected ammonia leak and high ammonia readings (detected by emergency responders less than an hour and a half prior to the dispatch) removed key safety system oversight and support that could have been provided by the firm's ammonia emergency response procedure.

2.6 Potential for greater injury and loss of life

[redacted] was given no indication by his immediate supervisor that the curling rink chiller was compromised and operating in an upset condition and the brine system contained dangerously high levels of ammonia. The job duties of this worker specifically included entrance into the compressor room on a regular basis. [redacted] was assigned to work, alone, the evening before the incident with no knowledge and no contingency plan in place to ensure his safety if further breakdown of the refrigeration system occurred. Four hours after [redacted] exited the workplace, the sequence of events that resulted in tragedy did in fact occur.

[redacted] was able to proceed unobstructed to the compressor room door [redacted] This initial exposure could have been much worse, depending on factors such as wind condition or further release of the ammonia. Given the high ammonia concentrations detected when responders arrived after the

911 call, it is likely that this person could have been overcome by ammonia gas and unable to leave the location without assistance.

The results of the ventilation testing indicate that expelled ammonia could have spread to other areas of the facility, such as the change rooms, hallways, offices, and user group areas for skating and martial arts, through the unsealed vestibule and the HVAC system. Had these areas been occupied at the time of the incident, other injuries to workers and the general public might have occurred.

3 Conclusions

3.1 Cause

3.1.1 A hole developed in the refrigeration system component, allowing for the intermixing of brine and ammonia

Over time, a corrosion pit inside a brine tube of a flooded ammonia chiller penetrated the tube wall so the brine and ammonia systems were no longer separated as intended. Both systems became contaminated and the refrigerant (ammonia) and heat exchange liquid (brine) were intermixing. The refrigeration system was no longer operating as intended, and was instead in an upset condition. The ammonia, which should have been contained in a pressure rated system, entered the non-pressure rated piping of the brine system, where it reacted and expanded creating a rise in pressure, and causing an unintentional release of ammonia into the compressor room.

3.1.2 Compromised refrigeration equipment failed when put into service

The chiller was put into service on October 16, 2017 at approximately 06:00 hours, after it was known that the chiller component had been compromised and leaked when filled with ammonia. Approximately 21 hours after it was put into service, automatic alarms signaled that there was an unintentional ammonia release in the compressor room, and the refrigeration system was shut down. Between the spring shut down and the fall start-up, there was no ammonia charge in the chiller, so the leaking into the brine did not reoccur until after the fall start-up on October 16th.

Efforts to remedy the upset condition and get the refrigeration system running again did not address the ammonia containment leak. Instead, these efforts increased the risk to workers of ammonia exposure through several new hazards: trapped pressures, cessation of circulation, and localized chemical reactions resulting from the intermixing chemicals were all hazardous conditions that evolved from the initial efforts to manage the upset condition. These hazardous conditions were not fully considered, identified, or mitigated by the occupational health and safety programs Fernie and CIMCO had developed to protect workers from workplace hazards associated with working around and repairing ammonia refrigeration systems.

The ammonia leak continued unchecked until a local saturation of the ammonia-brine mixture developed enough pressure to cause a pipe connection to fail.

There were indications that a failure of ammonia containment in the curling rink chiller had occurred six months prior to the day of the incident, which was confirmed though laboratory testing. Despite this, the plant was restarted the day before the incident in keeping with the usual operating schedule for the facility and the start of the curling season. Fernie did not have a system in place to address or assess the potential safety hazards associated with aging equipment during start-up, during operation, or when shutting down the equipment in an upset condition.

CIMCO did not provide Fernie with health and safety direction or caution against restarting the ice plant after the ammonia-containing system was demonstrated to have suffered a containment breach. Instead, CIMCO directed additional monitoring of the system.

CIMCO nor Fernie addressed the health and safety issue of high ammonia concentrations in the brine system, which was not designed to handle ammonia during operation.

3.2 Contributing factors

3.2.1 Health and safety systems did not mitigate risks to workers

Fernie’s workplace health and safety inspections and incident investigations were not conducted in relation to the refrigeration system during the initial breakdown. Important information was not communicated within the decision-making groups. Contingency and action plans were not developed to address hazardous conditions that were known to exist, including the presence of ammonia in the brine piping. Workers were not informed of the new hazards associated with their assigned job duties.

These factors reduced the effectiveness of the overall occupational health and safety program in the workplace, so the procedures intended to protect workers were not used adequately when responding to the ammonia problem. The inability of Fernie’s occupational health and safety program to detect and correct the initial indications of an ammonia leak six months prior to the incident, allowed hazardous workplace conditions to develop and continue unchecked up to the time of the incident. Notably, ammonia leak emergency procedures had not been reviewed and practised, so that important safety steps were overlooked prior to the commencement of restart activities for the leaking refrigeration system.

CIMCO did not have a stand-alone safe work procedure to mitigate the hazards to workers when dealing with refrigeration equipment in an upset condition. Key safety procedures intended to address the hazards associated with responding to unexpected ammonia releases were not used as intended. The field-level risk assessment forms were not effective for the recognition and prevention of the development of hazardous conditions before they evolved past the danger point and fatally injured the workers in the compressor room.

3.2.2 Incident response measures were not present

When the stage 2 mechanical failure occurred (loss of containment of the ammonia-brine mixture from the brine circulation system) and released high concentrations of ammonia gas, the Fernie firefighters had already been dismissed, and the automatic alarm systems had been disabled. There was no mechanism in place to alert any party that a serious incident had occurred. Workers in the room were not wearing adequate personal protective equipment for the exposure levels that they were exposed to. A rescue team was not at the ready, and when rescuers arrived, they did not have real-time information to work with. When monitoring systems were removed from service while the workers conducted maintenance on the compressor, interim measures should have been implemented to ensure that the workers in the room had back-up assistance at the ready in case of further toxic gas release.

Fernie had not reviewed the emergency procedures or conducted any practice drills for many years prior to the incident. When the upset condition occurred and Fernie’s workers responded to the first alarms, they were unfamiliar with the procedures, and important provisions prescribed by the procedures were overlooked.

3.2.3 Manufacturing process fostered preferential corrosion

The welding method employed during the manufacture of the chiller tubes caused the inclusion of unwanted porous iron oxide deposits in an intermittent pattern along the welded seams. The locations of these deposits became susceptible to higher-than-average corrosion in the presence of chemicals containing chlorides, such as the calcium chloride brine used in the ice-making equipment. The result was a hole in a tube, which allowed ammonia to enter a non-pressure-rated part of the equipment that was only designed to handle aqueous brine.

3.3 Other safety issues

3.3.1 Potential for further exposure and loss of life

The Fernie Memorial Arena’s makeup air was in close proximity to the ammonia vent stack and the emergency ventilation outlet on the roof. When the emergency ventilation system activated and venting occurred, released ammonia was able to be drawn into the building’s HVAC system and recirculated into the facility through floor and wall ducting. The compressor room was not sealed, so hazardous vapours were able to migrate into other parts of the facility. Had these locations been occupied at the time of the incident, there could have been additional injury from exposure to the ammonia by workers and other people inside the arena.

There was no perimeter security or watch personnel to prevent inadvertent exposure to the ammonia by other workers or the general public.

4 Health and safety

4.1 Actions taken by City of Fernie

The City of Fernie completely removed the ammonia-based refrigeration equipment from service and is in the process of installing a Freon-based refrigeration system in Fernie Memorial Arena.

4.2 Actions taken by Toromont Industries Ltd. (CIMCO Refrigeration)

After the incident, CIMCO published two safety bulletins for internal company use. Each bulletin includes a space for a worker to initial to indicate the bulletin has been reviewed.

On October 31, 2017, CIMCO published "Hazard Alert — Use and Limitations of Dresser Couplings." Dresser-type coupling is another name for the type of coupling that was used on the brine pipe in this incident. In this safety bulletin, CIMCO warns that such couplings "[do] not restrain against axial pipe movement." The bulletin states, in part:
CIMCO does not support the use of mechanical compression/Dresser-type couplings for joining two pipes together … It is always recommended to join pipe together via a welding process.

On November 8, 2017, CIMCO published "Hazard Alert — Risk of Liquid Expansion between Two Valves." This safety bulletin states, in part:

> [L]iquid trapped in or between two closed valves will see a rapid increase in pressure if the liquid is warmed up. Refrigerants such as ammonia can experience rapid pressure increases when the fluid is warmed. A 1°F increase in temperature can result in a 150 psi increase in pressure.
>
> NEVER TRAP A LIQUID BETWEEN TWO CLOSED VALVES UNLESS YOU HAVE VERIFIED PROPER CONTROLS ARE IN PLACE AND FUNCTIONING CORRECTLY TO RELIEVE OR PREVENT OVERPRESSURE.

4.3 Actions taken by WorkSafeBC

To facilitate field work during the investigation, WorkSafeBC developed and implemented a site-specific safety plan to protect the health and safety of WorkSafeBC personnel, contractors, and investigators from other agencies, including Technical Safety BC, the RCMP, and the two employers named in this report. (See Appendix B: WorkSafeBC Site-Specific Safety Plan.)

In November 2017, WorkSafeBC commenced a three-phase ammonia inspection initiative throughout B.C.

- Phase 1 involved 39 officers who conducted inspections of all 223 arenas in the province. More than 180 of those arenas were found to be using ammonia based refrigeration systems.

- Phase 2 of inspections focused on the activities of refrigeration contractors conducting installations, maintenance, and other activities involving ammonia systems.
- Phase 3 is currently under way and seeks to address process safety within industry sectors that use ammonia, such as food processing and industrial chemical manufacturing.

4.4 Violations and Orders:

4.4.1 City of Fernie

WorkSafeBC generated notice of incident 2017160530032, detailing the facts collected immediately after the incident.

During the investigation, WorkSafeBC identified the following violations by Fernie which are detailed in IR201816376004A:

Workers Compensation Act:

- Section 115(1)(a) — Failure to ensure the health and safety of all workers present at the workplace at which this employer's work was being carried out

Occupational Health and Safety Regulation:

- Section 3.5 — Failure to ensure that regular inspections of the workplace were conducted at intervals to prevent the development of unsafe working conditions
- Section 4.3(1)(a) — Failure to ensure that the equipment in the compressor room was capable of safely performing the function for which it was used
- Section 5.97(3) — Failure to review the emergency plan annually
- Section 5.102 — Failure to train workers and conduct drills to test the adequacy of the procedures so that workers and supervisors were familiar with their roles and responsibilities when the plan was implemented
- Section 6.119 — Failure to develop and implement an exposure control plan for ammonia in the workplace in accordance with section 5.54
- Section 6.132 — Failure to ensure that the servicing and maintenance of equipment and machinery associated with ammonia addressed all critical components
- Section 8.33 — Failure to ensure that respiratory equipment as needed was selected in consultation with workers who might be exposed to ammonia and with the safety committee, and to ensure that such respiratory equipment was appropriate for the level of ammonia that workers might be exposed to

WorkSafeBC also referred Fernie to the following sections:

- Section 130 of the Act — Duties and functions of a joint committee

- Section 3.8 of the Regulation — Ensuring that a worker and employer representative participate in workplace inspections
- Section 3.28 of the Regulation — Having a worker and employer representative present for investigations
- Section 4.3(1)(b)(i) of the Regulation — Ensuring that the VC and HC couplings were used in accordance with manufacturer's instructions
- Section 4.11 of the Regulation — Ensuring that putting into operation equipment, machinery, and a work process will not expose a person to undue risk
- Section 4.12 — Intentional circumvention of safeguards, specifically the ammonia liquid high-level shutdown switches
- Section 5.11(b) of the Regulation — Hazardous product piping systems and vessels
- Section 6.131 of the Regulation — Piping systems for toxic process gases
- Section 10.2 of the Regulation — Lockout of all sources of hazardous energy
- Section 12.10 of the Regulation — Identifying unsafe equipment
- Section 12.13 of the Regulation — Marking physical hazards

4.4.2 Toromont Industries Ltd. (CIMCO Refrigeration)

WorkSafeBC generated notice of incident 2017160530032, detailing the facts collected immediately after the incident.

During the investigation, WorkSafeBC identified the following violations by Toromont Industries Ltd. (CIMCO Refrigeration):

- Section 115(1)(a)(i) of the Act — Failure to protect the health and safety of CIMCO workers: The firm did not ensure the health and safety of the employers' worker by failing to fully consider and/or implement the employers' ammonia emergency response procedure after an unexpected release of ammonia was known to have occurred at the customer location, and allowing maintenance work to be performed, prior to ensuring the effective mitigation and control of all workplace hazards present in the workplace where the work was assigned.
- Section 115(2)(e) of the Act — Failure to ensure the health and safety of the employers' workers by not assessing the risk to workers and/or not instituting effective hazard controls, not developing effective safe work procedure(s), and did not instruct, provide information, and training to workers (the Refrigeration Mechanic and the Refrigeration Supervisor), assigned to work, or supervise work, on a refrigeration system where the ammonia was known to be leaking into the brine system, which was not intended to contain ammonia.

WorkSafeBC also referred Toromont Industries Ltd. (CIMCO Refrigeration) to the following sections of the Regulation:

- Section 8.9 — Worker's responsibilities for wearing personal protective equipment

- Section 10.2 — Requirement to ensure that equipment is locked out prior to conducting maintenance activities

Appendixes

The following appendixes can be found in the PDF accompanying this report:

- Appendix A: Safety Information about Ammonia
- Appendix B: WorkSafeBC Site Specific Safety Plan
- Appendix C: Forensic Engineering Report — Acuren Group Inc.
- Appendix D: Refrigeration Subject Matter Expert Technical Report — Strong Refrigeration Consultants Inc.
- Appendix E: As-found Valve Positions Drawings