Appendix C: Site Description and Scene Documentation

The photos contained in this appendix were taken or collected as part of Technical Safety BC's investigation and are included to supplement the discussion in the report.

C0: Site, System and Component Descriptions

An overview of the following site, system and components is helpful to understand aspects of the Fernie Memorial Arena, the refrigeration system and the components involved with the incident.

Class T Machinery Room

The mechanical room at the Fernie Memorial Arena that contained the refrigeration equipment is a 'Class T Machinery Room'. Class T machinery rooms are designed as non-occupied spaces with restricted access. Their objective is to house refrigerant and system components while providing a degree of isolation from the occupied spaces in the event of a refrigerant leak. Access is restricted to authorized persons and limited to necessary operation and maintenance activities.

Ammonia sensors, alarms, room ventilation and the room configuration is designed to alert operators and limit leaking refrigerant from entering the occupied spaces. Ventilation air for the room is provided to and from the mechanical room directly from the outside. Controls are provided to shut the refrigeration system down and display the amount of ammonia measured by the ammonia detection system outside of the mechanical room.

Ammonia Refrigeration and Brine Cooling System at Fernie Memorial Arena

The Fernie Memorial Arena utilized an indirect vented closed compression refrigeration system to cool the arena and curling ice surfaces. This system uses a refrigerant to remove heat from a secondary coolant in the heat exchanger or chiller. The process evaporates the refrigerant which is then compressed and condensed back into a liquid to be re-circulated back to the chiller. The secondary coolant remains a liquid and is pumped to the floor and back to the chiller to be cooled again as shown in Figure C0-1 below.

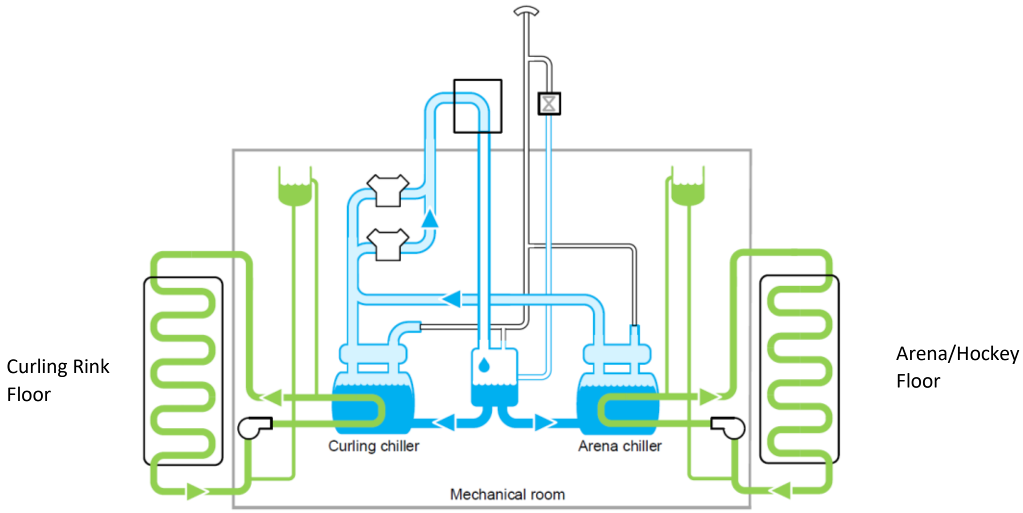


Figure C0-1: Ammonia Refrigeration and Brine Systems at Fernie Memorial Arena. Refrigerant is shown blue and coolant is shown green.

Ammonia was the refrigerant utilized to cool two independent brine coolant systems that circulated cold brine to the arena and curling floors. The two brine systems were independent and with a dedicated chiller for each.

All of the ammonia, refrigeration system and mechanical components are located in the mechanical room, with the exception of the condenser and emergency/pressure relief discharge piping & diffuser, which are located immediately outside for functional purposes. Only the chilled brine is circulated within occupied spaces of the building.

Ammonia

Ammonia is a common refrigerant due to its thermal properties, relatively low environmental impact and low cost as compared to other refrigerants. Ammonia boils at -33°C when unpressurized (atmospheric pressure of 101.3 kilopascals (kPa) (14.7 psi)) and condenses from vapour to liquid if pressurized to 1166 kPa (169 psi) at 30°C.

Ammonia has a high expansion ratio of over 800:1 meaning that a small volume of liquid when vapourized will command a large volume at room temperature. For example, a one litre (1L) open bucket of liquid ammonia (approximately 1.5lbs) at -33°C, if vapourized will expand to occupy a volume of over 800L at standard room temperature and atmospheric pressure. Ammonia expanding into a space will have a cooling effect before ambient temperatures will complete the expansion.

The density of ammonia vapour is approximately 60% of the density of air and will naturally rise toward the ceiling within a room or up and away from the ground. The movement of ammonia vapour will however be highly affected by air currents and pressures and other outside meteorological conditions.

Ammonia is a colourless gas with a strong odour. It is very toxic, corrosive and flammable at concentrations between 15.5% and 27% with an ignition temperature of 650°Celsius (C). The Canadian Centre for Occupational Health and Safety ammonia fact sheet contains additional information.

Exposure (ppm ammonia in air)	Signs and Symptoms
50	Irritation to eyes, nose and throat (2 hours exposure)
100	Rapid eye and respiratory tract irritation
250	Tolerable by most people (30–60 minutes exposure)
700	Immediately irritating to eyes and throat
>1,500	Pulmonary oedema, coughing, laryngospasm
2,500-4,500	Fatal (30 minutes exposure)
5,000-10,000	Rapidly fatal due to airway obstruction, may also cause skin damage

Table C0-1: Toxic effects following acute exposure to ammonia by inhalation from Ammonia Toxicological Overview – Public Health England

Exposure Limits to ammonia are identified by WorkSafeBC as follows:

Exposure Level (ppm)	Exposure Limit
25	Maximum allowable concentration averaged over an 8-hour period
35	Maximum allowable short-term exposure (15 minutes)
300	Immediately dangerous to life and health (IDLH)

Table C0-2: Ammonia Exposure Limits

Brine

The coolant that is pumped through the chillers and out to the curling and arena floors at the Fernie Memorial Arena was a 22% calcium chloride (salt) brine solution. This brine solution can be chilled to temperatures of approximately -23°C without freezing. A corrosion inhibitor is added to the brine solution to help counter the corrosive effects that the calcium chloride solution has on the carbon steel piping and chiller components.

Curling Brine Chiller

The curling brine chiller is a shell and tube heat exchanger that transfers heat energy from one liquid to another without mixing the two. The Fernie Memorial Arena incorporated two-pass shell and tube chillers for both the arena and curling systems. The 'warm' brine is pumped into the chiller where it splits and flows through numerous tubes to increase the heat transfer surface area contact.

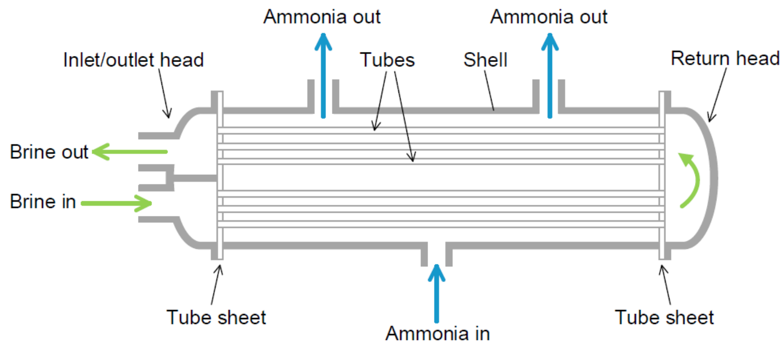


Figure C0-2: Generic diagram of a two-pass flooded chiller similar to that used at the Fernie Memorial Arena

The chiller tubes are contained within a cylindrical shell where cold liquid ammonia is fed into the shell bottom through a solenoid and expansion valve. A level controller controls the operation of the solenoid valve to maintain the liquid level at a pre-determined setting. High-level cut-off float switches and surge vessels protect the compressors from exposure to liquid ammonia.

Shell pressure on the ammonia side is typically maintained between 15 psi and 35 psi by the compressor settings. Liquid ammonia on the outer surface of the tubes receives heat from brine circulating through the tubes, resulting in flashing of liquid ammonia into vapour on the shell side and colder brine on the secondary side.

The heat transfer process within the chiller results with warm brine entering the tube side, being chilled by the ammonia on the shell side and then cold brine exiting to be pumped back out to cool the ice floor of the curling rink or arena.

Brine Expansion Tank

Brine systems incorporate an expansion tank that is mounted at an elevated location. The brine expansion tank allows for the liquid volume within the system to expand and contract during various operating conditions and ensures a liquid presence and small pressure at the pump inlet.

The brine expansion tanks are open to the mechanical room atmosphere to allow for trapped air to escape and to ensure that the brine system does not become pressurized. The brine system is not required to be designed to withhold pressure and may only be anticipated to experience pressures associated with secondary coolant circulation.

Brine System Pipe Couplings

Within the mechanical room, the brine system piping was of carbon steel construction and welded at joint locations. There was one pipe segment on the curling brine system that utilized straight couplings rather than welded joints to connect the pipe to the system. One coupling was installed in a vertical orientation where the fluid exited the curling chiller and the second coupling joined the other end of the pipe segment to the brine pipe that was routed to the curling floor. This pipe segment contained two 90 degree bends that routed the pipe from the chiller, towards the floor and under the other chiller.

The straight line pipe coupling forms a compression fit to seal in liquid however it does not act as a structural member of the piping system. Piping utilizing straight line compression fit couplings must be structurally supported on either side of the coupling to prevent pipe movement or separation. The current manufacturers catalogue associated with the couplings used at the Fernie Memorial Arena contained the caution shown in Figure C0-3. A 1980 catalogue contained the following statement: *Proper restraint of pipes, especially plastic pipes, is necessary to resist pull out, due to pressure, temperature and surge effects, among other forces.*

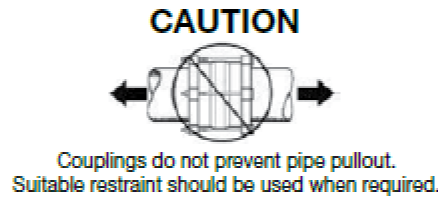


Figure C0-3: Caution statement contained in the coupling manufacturer's catalogue.

Mixing of liquid ammonia and brine

Ammonia (NH3) has a strong affinity for water, meaning it readily reacts chemically to form an ammonium hydroxide (NH4 + OH) solution. The chemical reaction is exothermic, producing heat as a by-product of the chemical reaction. Once the water becomes saturated and cannot absorb additional ammonia, any added ammonia will readily expand out of the solution or form a liquid ammonia layer on top depending upon the temperature and pressure conditions. The chemical reaction is reversible and ammonia will 'off-gas' from an ammonium hydroxide solution and the 'off-gas' rate will increase with the addition of heat.

C1: Outside Arena

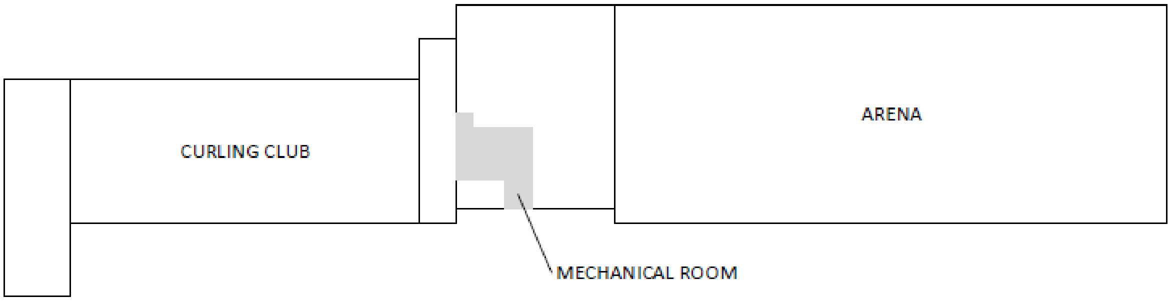


Figure C1-1: Plan view of Fernie Memorial Arena and Curling Club

Photo C1-1: Outside arena view looking at mechanical room door on October 18, 2017.

Photo C1-2: Outside arena looking at the mechanical room door (blue), furnace room (beige) and fire box (red)

C2: Mechanical Room

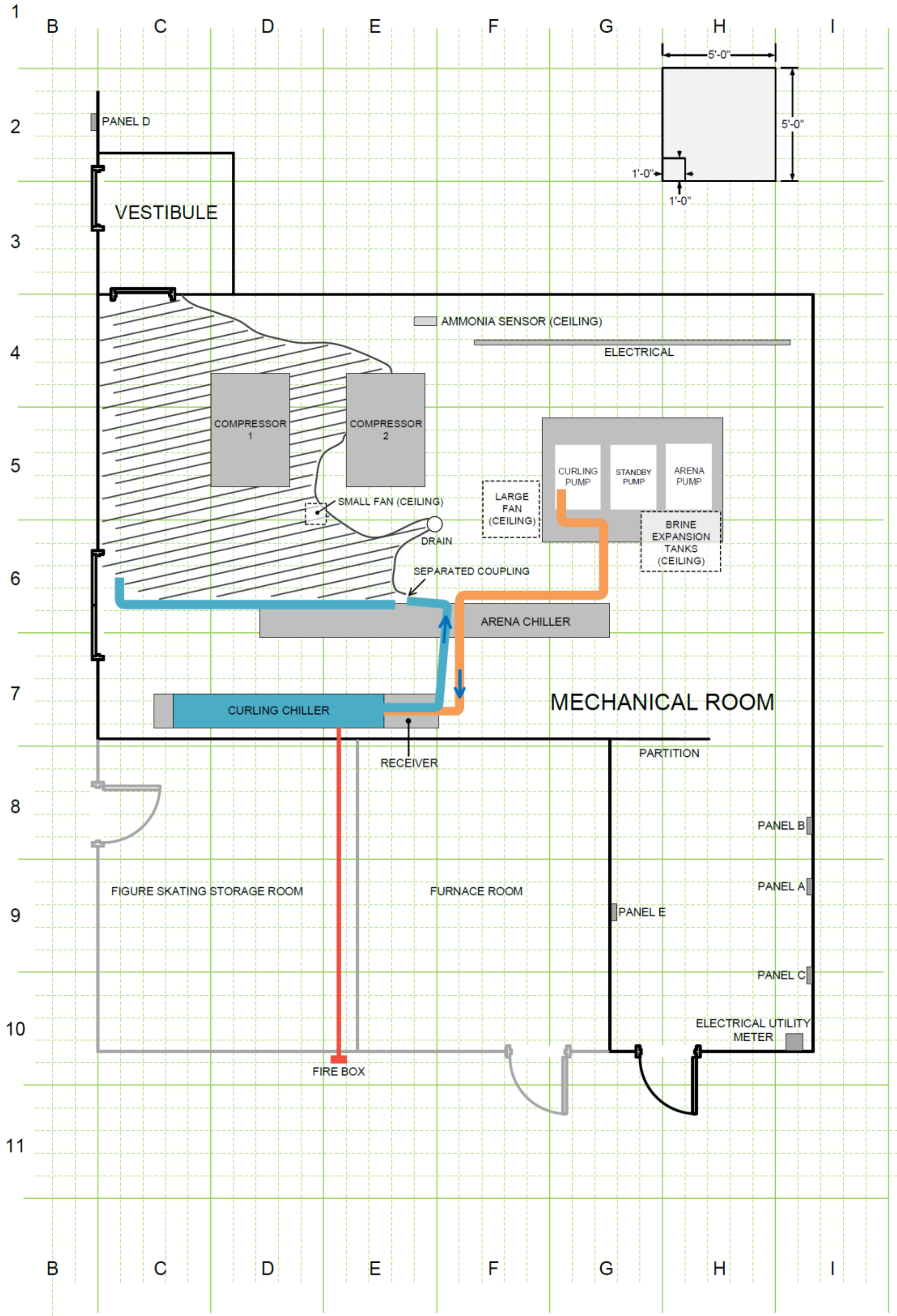


Figure C2-1: Plan view of mechanical room

Photo C2-1: View looking from corner with vestibule door showing compressors in the foreground, expansion tanks near the ceiling and the black insulation covering the arena brine system chiller and surge vessel.

Photo C2-2: Arena pump, standby pump, curling pump. These pumps are visible in the background of photo C2-1.	**Photo C2-3:** View looking onto the east wall showing Compressors 1 and 2. The compressors are visible in the foreground of photo C2-1.

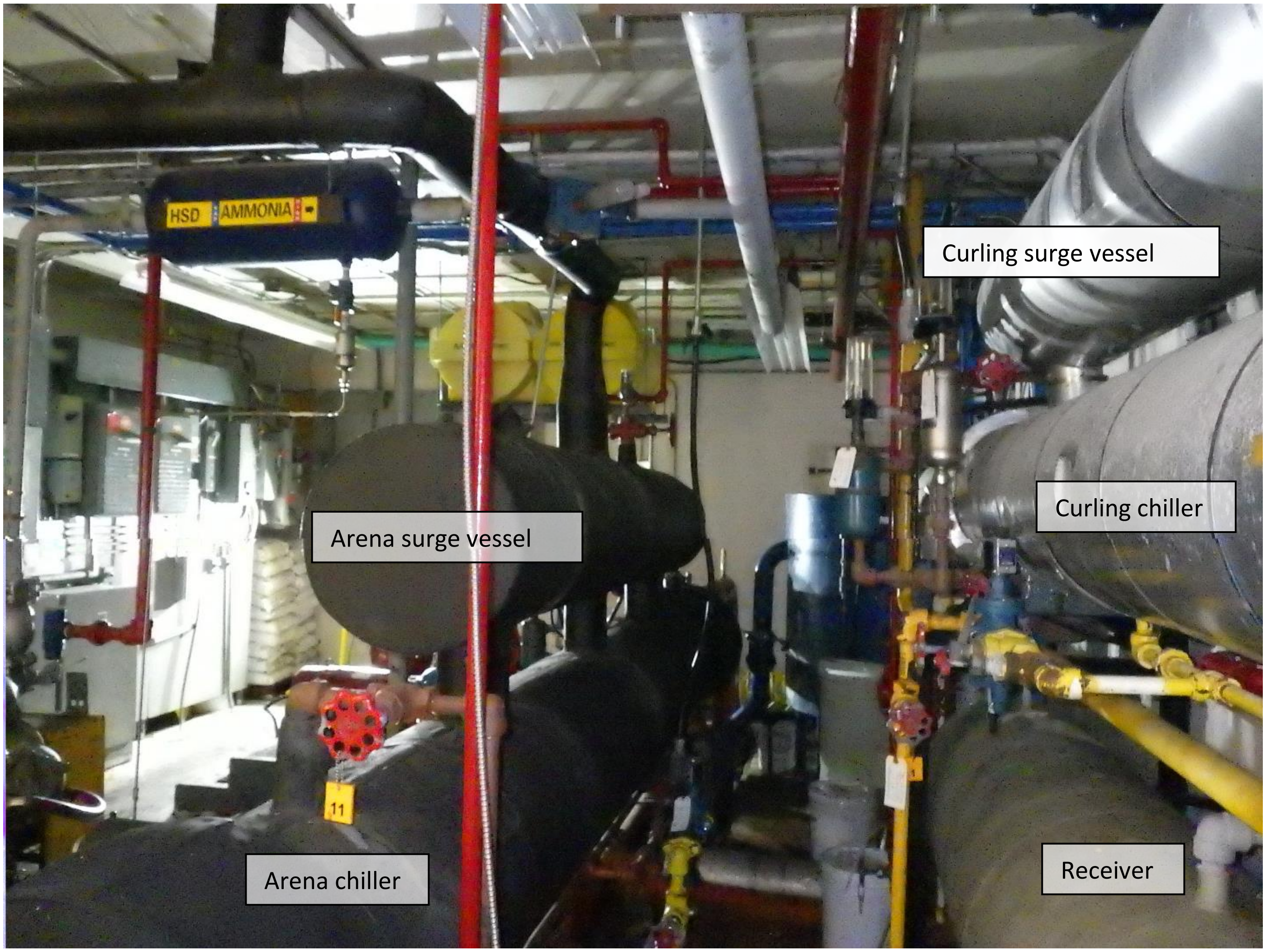


Photo C2-4: Looking toward the north wall between the arena and curling chillers. Receiver is installed below the curling chiller.

C3 Curling Brine System Chiller

Photo C3-1: Curling chiller with the brine inlet and outlet piping removed. The photo below shows the curling chiller with its head removed, exposing the tube sheet.

Photo C3-2: Curling chiller, head removed. The brine inlet/outlet tube sheet at the north end of the chiller. Debris and residue is visible on the tubes.

Photo C3-3: Return end tube sheet (south end) of the curling chiller. Debris and residue is also visible on the tubes and sheet.

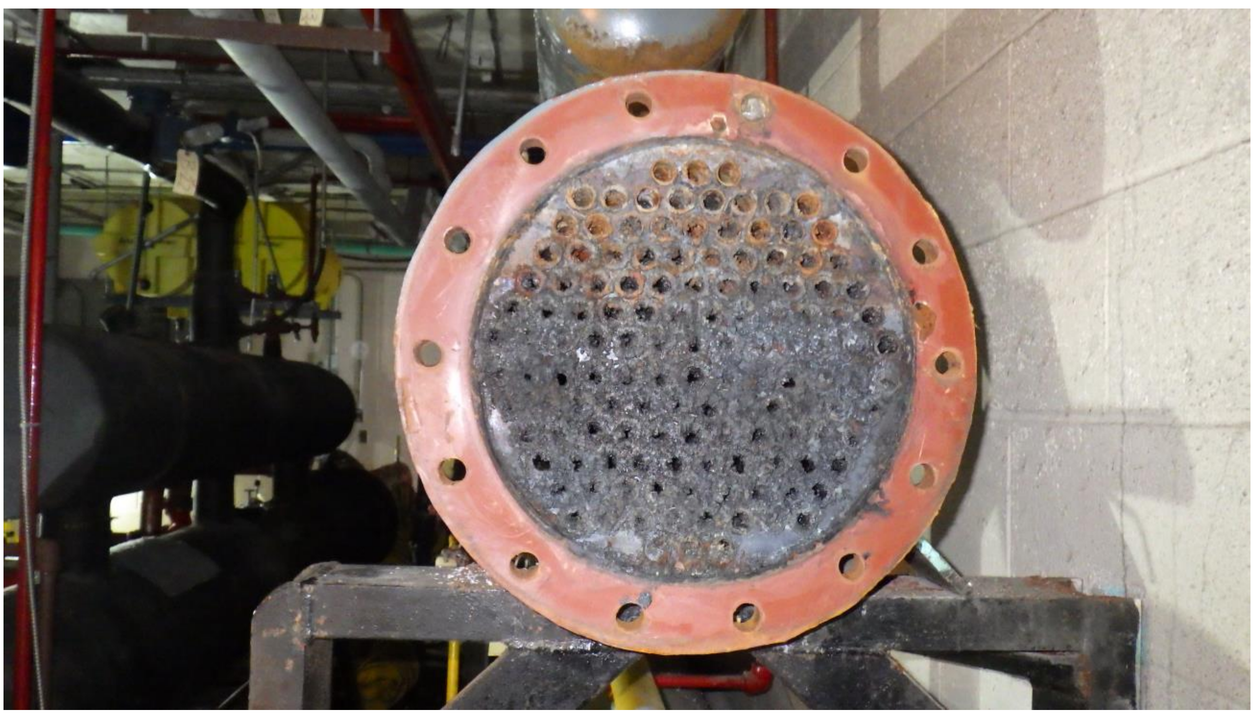


Photo C3-4: Curling chiller, tube sheet upon opening in January 2018 showing residue.

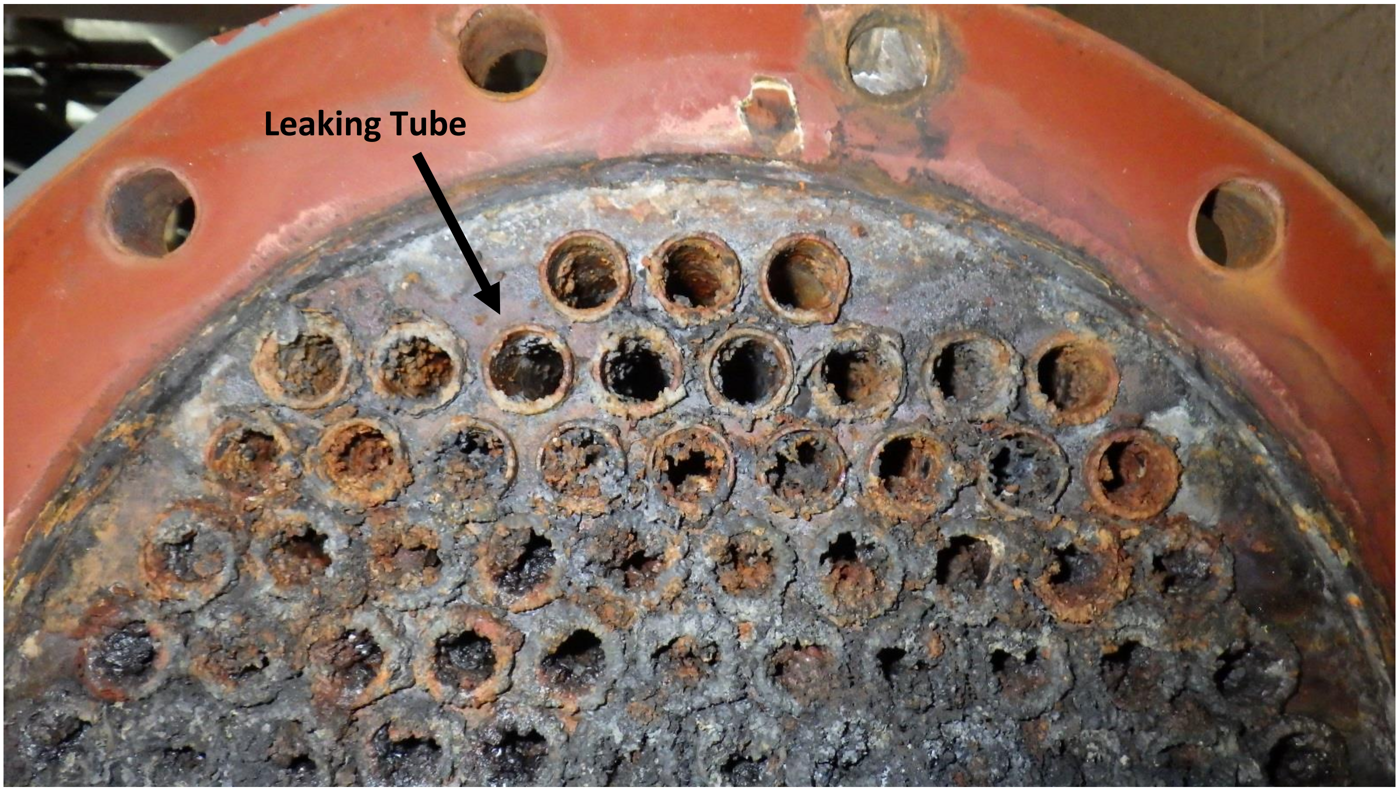


Photo C3-5: Close up of upper tubes from return end of chiller upon opening in January 2018.

Photo C3-6: Curling chiller return head

Photo C3-7: Curling chiller inlet/outlet head

Photo C3-8 and Photo C3-9 (below): Chiller with shell section and top three tubes cut away at return end – white scale indicates brine leak into shell (ammonia) side of heat exchanger. Below shows leaking tube removed with scale deposits and spray patterns on adjacent tubes.

Photo C3-10 (above) and Photo C3-11 (below): Above shows evidence of spray from tube (brine) side into shell (ammonia) side. Photo C3-11 shows close-up of inside surface of the tube and leak location showing erosion of metal from ammonia leak into tube.

Photo C3-12: Curling chiller (with insulation) showing the ammonia liquid inlet configuration. Valve positions are noted in Appendix B.

Photo C3-13: Manufacturer's nameplate – Curling System Brine Chiller – Fernie Memorial Arena. Date of manufacture identified as 1986. This chiller was approximately 31 years old at the time of failure

C4 Ammonia compressors

Photo C4-1: Compressor #2. Vestibule door and Compressor #1 in the background.

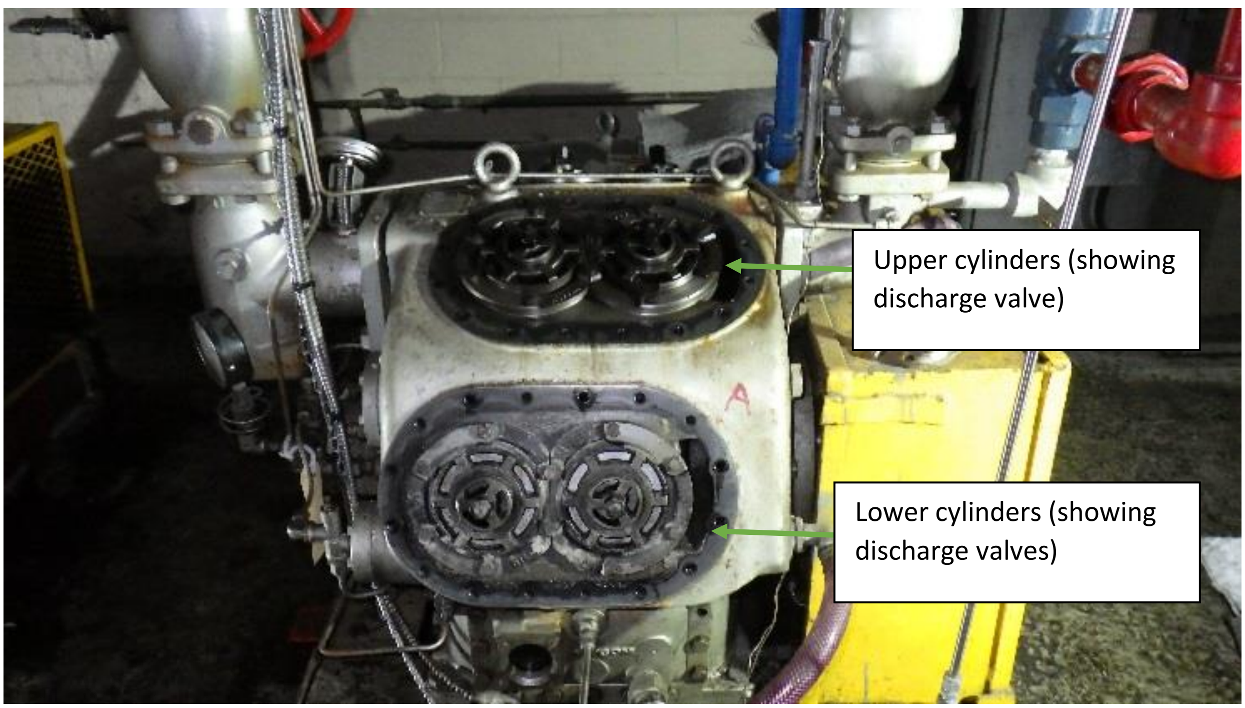


Photo C4-2: Compressor #2 (Compressor #1 similar) with valve covers removed. The lower discharge valves showed salt crystal build up. The upper discharge valves had less salt crystals on the discharge side of the valves and more crystals were present on top of the pistons (see Photo C4-4).

Photo C4-3: Close up of the lower valves in photo C4-2. Build-up of salt crystals from brine around the valves compressors #1 and #2.

Photo C4-4: Salt deposits/residue from the brine on one of the compressor's upper piston

C5 Separated Coupling

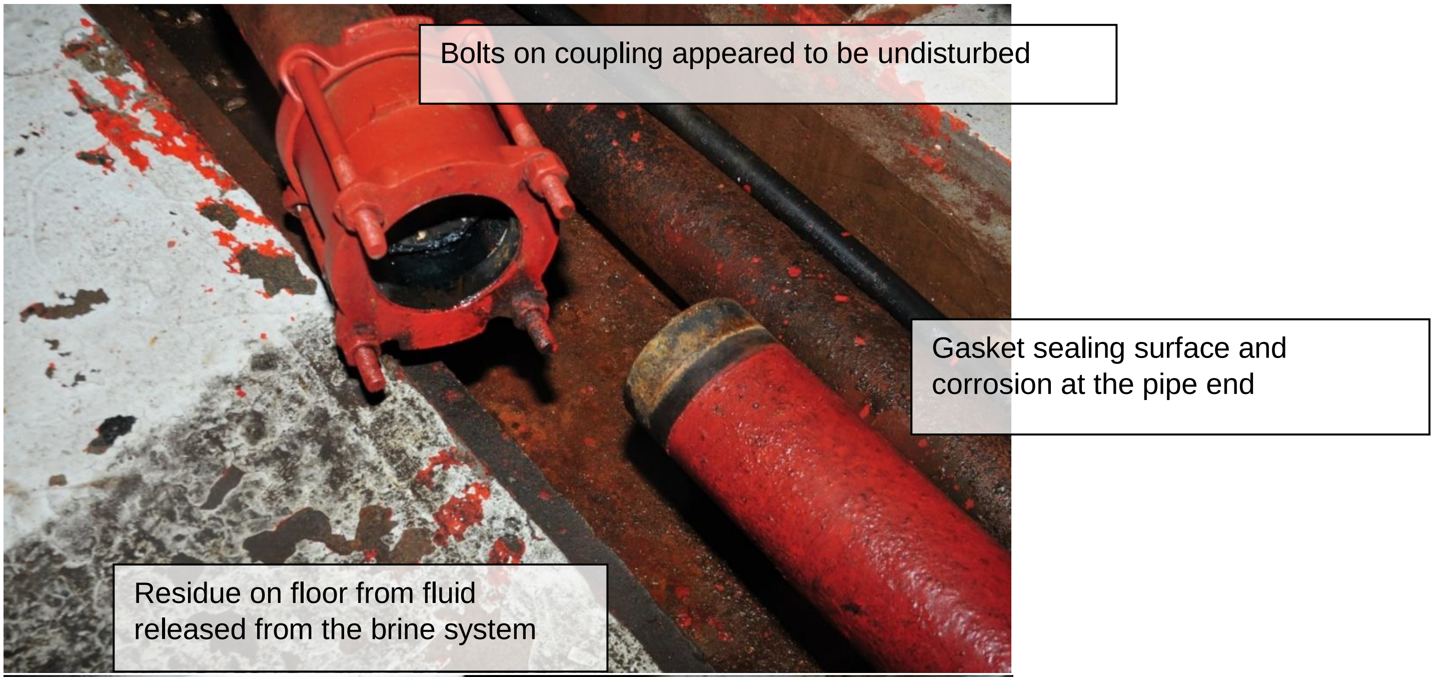


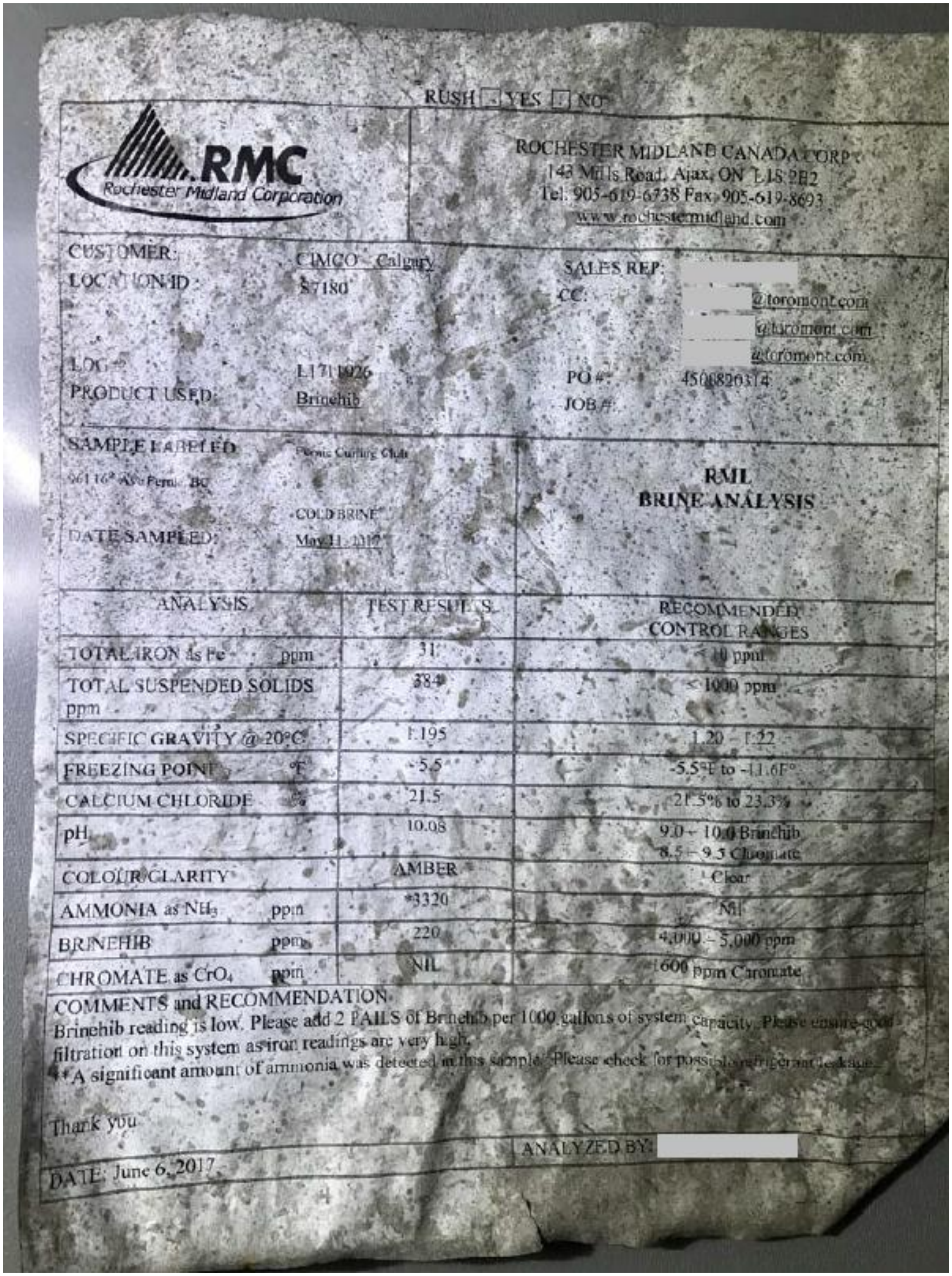
Photo C5-1 and **Photo C5-2:** Separated brine system coupling.

Photos C5-1 and C5-2 show the coupling dislodged from the piping. The report discusses the configuration of the piping components observed after the incident.

C6: Brine spray

Photo C6-1: SE corner of the mechanical room ceiling (above the receiver, curling chiller and surge drum).	**Photo C6-2:** SW corner of the mechanical room (above the door to vestibule). Brine spray is seen on the ceiling and walls below. The arrow indicates blue/turquoise discolouration on the copper pipe from exposure to ammonia.

Photos C6-3 and **Photo C6-4:** View of opened books contaminated with brine spray on a shelf on the mechanical room's south wall. Note the shadowing from spray, suggesting that the spray was directional and projected at and around different components (not evenly misted or distributed throughout the mechanical room).



RUSH ☐ YES ☐ NO

RMC Rochester Midland Corporation

ROCHESTER MIDLAND CANADA CORP.
143 Mills Road, Ajax, ON L1S 2H2
Tel. 905-619-6738 Fax. 905-619-8693
www.rochestermidland.com

CUSTOMER: CIMCO – Calgary
LOCATION ID: S7180
SALES REP: [redacted]
CC: [redacted]@toromont.com
[redacted]@toromont.com
[redacted]@toromont.com
LOG #: L171926
PO #: 4500820314
PRODUCT USED: Brinehib
JOB #:

SAMPLE LABELED: Fernie Curling Club
961 16th Ave Fernie, BC
COLD BRINE
DATE SAMPLED: May 31, 2017

RMIL
BRINE ANALYSIS

ANALYSIS		TEST RESULTS	RECOMMENDED CONTROL RANGES
TOTAL IRON as Fe	ppm	31	10 ppm
TOTAL SUSPENDED SOLIDS ppm		384	< 1000 ppm
SPECIFIC GRAVITY @ 20°C		1.195	1.20 – 1.22
FREEZING POINT	°F	-5.5	-5.5°F to -11.6F°
CALCIUM CHLORIDE	%	21.5	21.5% to 23.3%
pH		10.08	9.0 – 10.0 Brinehib 8.5 – 9.5 Chromate
COLOUR/CLARITY		AMBER	Clear
AMMONIA as NH_3	ppm	*3320	Nil
BRINEHIB	ppm	220	4,000 – 5,000 ppm
CHROMATE as CrO_4	ppm	NIL	1600 ppm Chromate

COMMENTS and RECOMMENDATION:
Brinehib reading is low. Please add 2 PAILS of Brinehib per 1000 gallons of system capacity. 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.

Thank you

ANALYZED BY: [redacted]

DATE: June 6, 2017

Photo C6-5: Brine Analysis Report for the curling system dated June 6, 2017 found in the mechanical room. Identical copies of this report were obtained from the City of Fernie, Cimco and the testing laboratory (Rochester Midland Corporation).

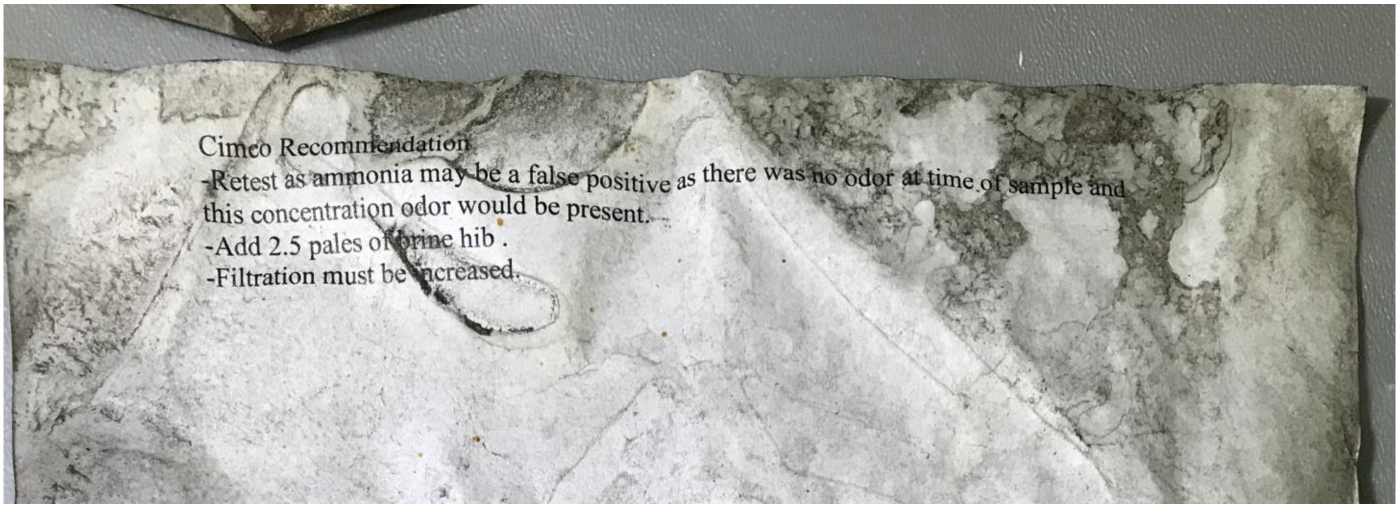


Photo C6-6: Paper found in the mechanical room near the brine analysis report dated June 6, 2017.

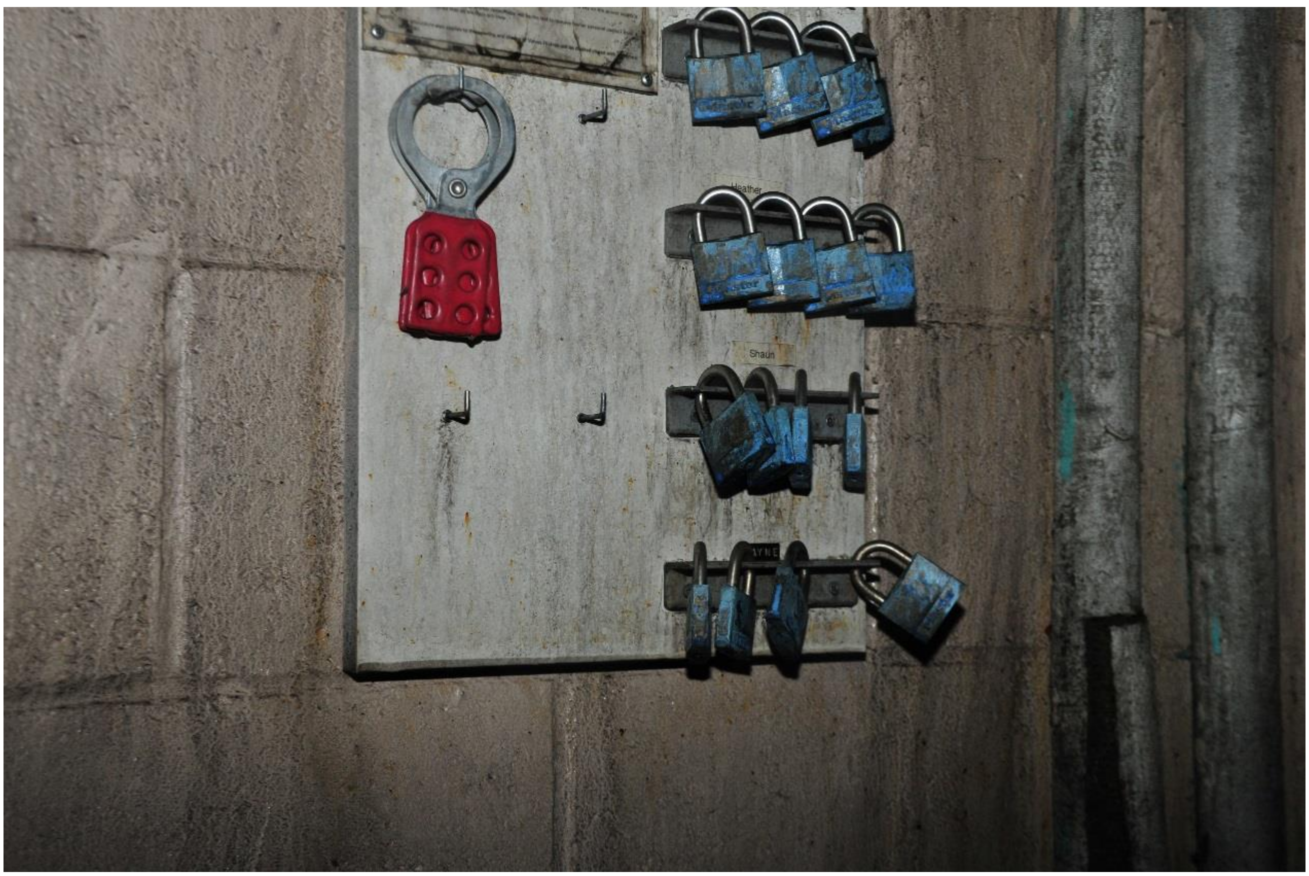


Photo C6-7: Copper locks showing blue corrosion due to ammonia exposure.

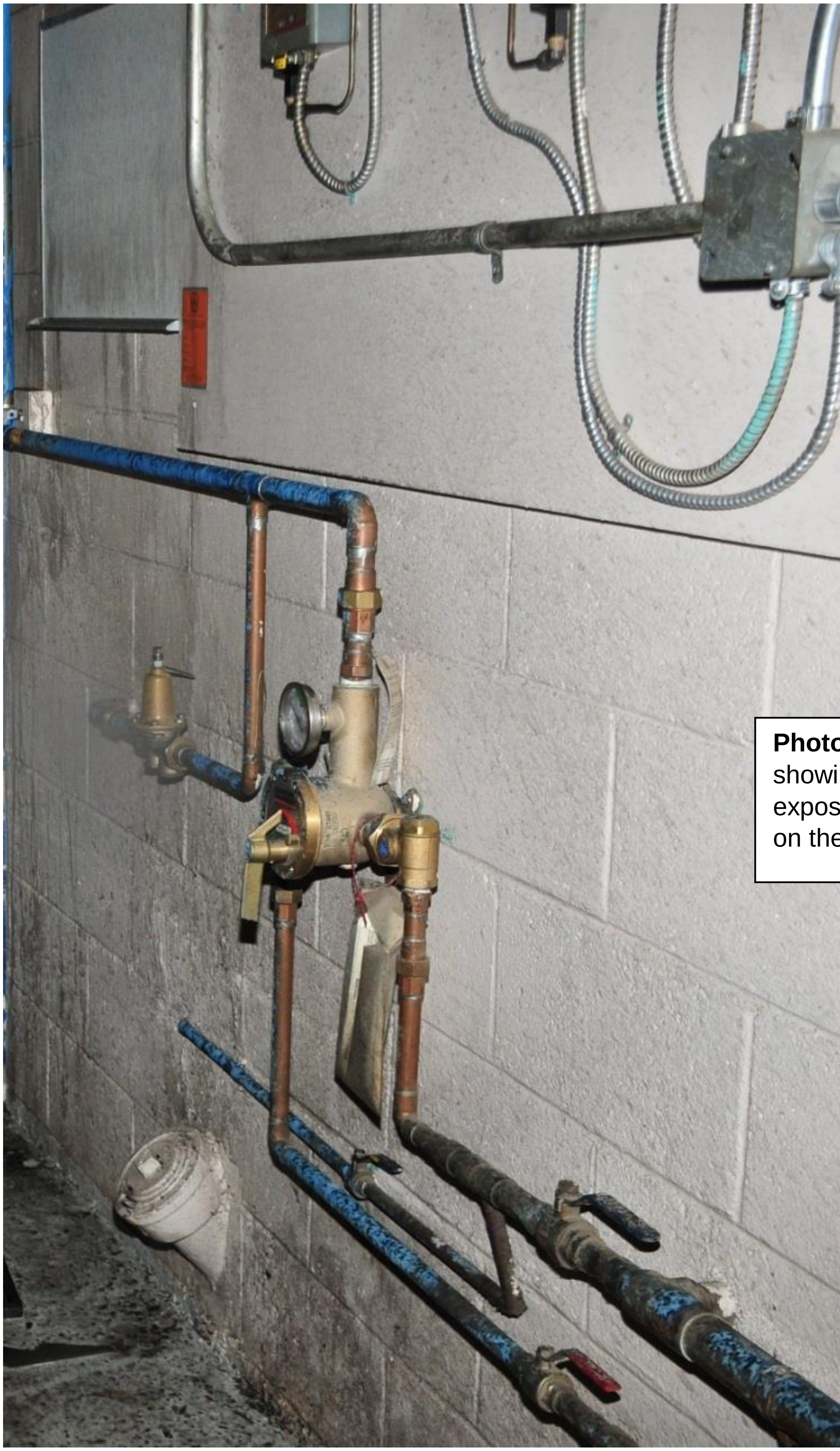


Photo C6-8: Exposed copper piping showing corrosion from ammonia exposure. Brine spray is also visible on the wall and floor surfaces.

Photo C6-9: Projected contents of the brine piping from the separating coupling.

Photo C6-10: Door between mechanical room and vestibule showing gap under door.

Photo C6-11: Door between vestibule and arena did not incorporate a seal at bottom.

C7: Figure skating storage room

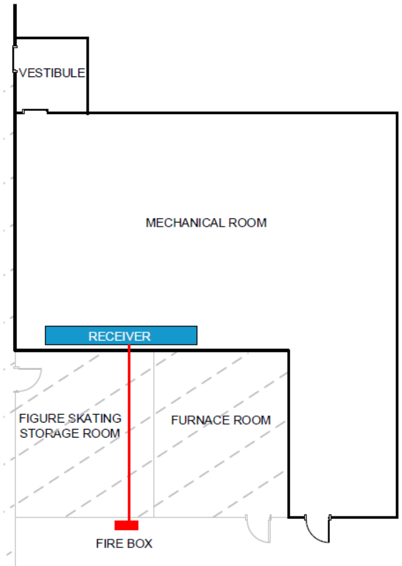


Figure C7-1: The emergency discharge piping (red) extends from the receiver (in the mechanical room) to the firebox on the building's exterior. The piping is routed through the figure skating storage room and can be seen in the photo below (along the wall parallel to the ceiling).

Photo C7-1: Figure skating storage room

Photo C7-2: Close up of the emergency discharge piping from the mechanical room into the figure skating storage room. The photo shows a costume suspended from the piping.

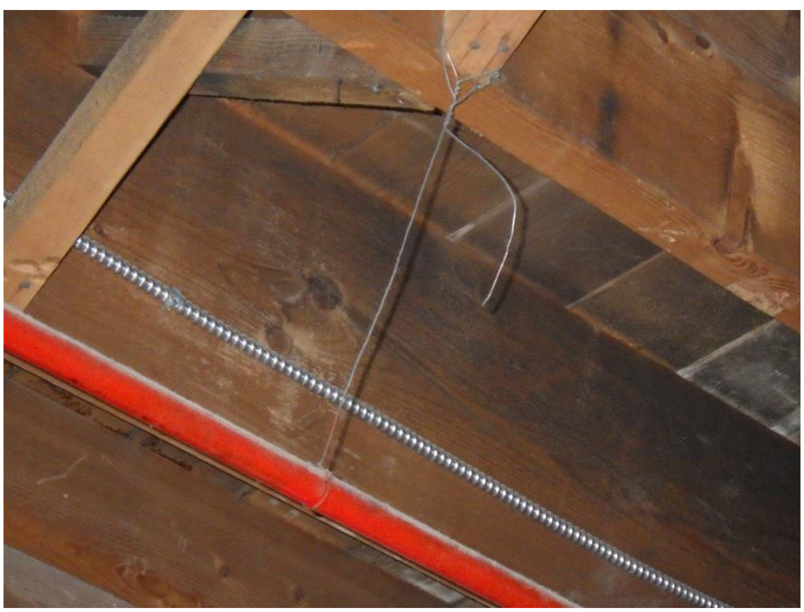


Photo C7-3: Discharge pipe was supported mid-span to ceiling structure by a thin wire.