

Ammonia Liquid Leak Incident Case Study

Date Incident Occurred: January 15, 2011 at approximately 7:15 PM

Area Location of Incident: Upper Midwest, United States

Plant Location of Incident: Blast Area

Weather Conditions: 16° F, 77% humidity,
Wind speed: 11.5 mph (North),
Sky condition: overcast with light snow

Summary of the Incident

This case study describes an estimated release of 4,074 lb_m of low temperature liquid anhydrous ammonia into a stationary blast freezing cell within a production facility. The release occurred due to mechanical integrity loss of an evaporator fan motor mount. The failed motor mount allowed the evaporator fan to strike the attached coil severing refrigerant tubing in the unit. The leak persisted for more than 8 hours before facility personnel could positively identify the leak source and take appropriate steps to mitigate the leak. No injuries occurred but the plant suffered significant product loss (~\$1MM) and lost production (~\$7.5MM) due to the incident.

Key Lesson's Learned

- Improvements are required for the mechanical integrity inspections and tests of evaporators, ammonia detection system, and key refrigeration system isolation valves.
- Improved access to evaporator units is required.
- Better logs and shift-to-shift communication is required.

A number of other lesson's learned as well as recommendations for preventing future similar incidents are provided in the body of this case study.

Incident Type (check all that apply):

<input type="checkbox"/>	High pressure vapor leak	<input type="checkbox"/>	High pressure liquid leak	<input type="checkbox"/>	Near-miss (no release)
<input type="checkbox"/>	Low pressure vapor leak	<input checked="" type="checkbox"/>	Low pressure liquid leak	<input type="checkbox"/>	Other (specify):

Comments:

The leak source was pumped liquid ammonia from a low-temperature (-40°F/-40°C) recirculator.

Incident precursors (check all that apply)

<input type="checkbox"/>	Corrosion	<input type="checkbox"/>	Impact damage	<input type="checkbox"/>	Operation error
<input type="checkbox"/>	Hydraulic shock	<input type="checkbox"/>	Power outage	<input type="checkbox"/>	Control failure
<input type="checkbox"/>	Upset condition	<input type="checkbox"/>	Maintenance procedure	<input type="checkbox"/>	Ammonia loading
<input checked="" type="checkbox"/>	Mechanical integrity loss	<input type="checkbox"/>	Overpressure	<input type="checkbox"/>	Other (specify): <i>Failed fan motor mounting bolts.</i>

Comments:

Chronic and excessive vibration on the unit enabled the motor mount bolts to fail.

Involved equipment (check all that apply)

<input type="checkbox"/>	Compressor (high stage)	<input type="checkbox"/>	Condenser, evaporative	<input type="checkbox"/>	Vessel, high pressure rec.
<input type="checkbox"/>	Compressor (booster)	<input type="checkbox"/>	Condenser, shell-and-tube	<input checked="" type="checkbox"/>	Vessel, recirculator
<input type="checkbox"/>	Compressor (pump-out)	<input type="checkbox"/>	Pump, transfer	<input type="checkbox"/>	Vessel, transfer drum
<input type="checkbox"/>	Valve, stop	<input type="checkbox"/>	Pump, recirculator	<input type="checkbox"/>	Vessel, oil pot
<input type="checkbox"/>	Valve, regulator	<input type="checkbox"/>	Piping	<input checked="" type="checkbox"/>	Electrical, motor
<input type="checkbox"/>	Valve, other (specify):	<input checked="" type="checkbox"/>	Evaporator, air-cooling	<input type="checkbox"/>	Electrical, starter
<input type="checkbox"/>	Valve, pressure relief	<input type="checkbox"/>	Evaporator, shell-and-tube	<input type="checkbox"/>	Temporary connections
<input type="checkbox"/>	Valve, self-closing ball	<input type="checkbox"/>	Evaporator, plate-and-frame	<input type="checkbox"/>	Instrumentation
					Other (specify): <i>Electric motor supports.</i>

Impact of incident (check all that apply)

On-site		Off-site, public		Off-site, environment	
	Minimal impact (no injuries, no production loss)	X	None	X	None
	Minor impact (minor injury, one or more line shutdown less than ½ shift)		Public-reported smell		Minor impact (known but isolated damage to area flora or fauna)
	Intermediate impact (multiple minor injuries, one or more lines shutdown one or more shift)		Public evacuation		Major impact (significant damage to area flora or fauna)
X	Major impact (multiple acute injuries, plant evacuation, significant financial loss)		Public injury		Unknown
	Catastrophe (in-patient hospitalization of 3 or more employees, plant shutdown for longer than one day)		Public fatality		
	Fatality		Unknown		
	Multiple fatalities				

Comments:

- Release occurred inside of the plant and no off-site consequences resulted from the release. External authorities were notified but did not respond.
- The incident required area relocation of plant personnel for their protection.
- No injuries resulted from the incident.
- The incident caused a significant business interruption at the plant with production stopping during the late evening of 1/15/2011 and not resuming until the morning of 1/20/2011.
- The estimated financial impact of the incident included:
 - \$1MM in product loss (due to contamination)
 - \$7.5MM+ in downtime and unfilled order loss

Details of the Incident

Background:

This facility is a production plant and the latter part of the production process involves moving finished products into stationary blast freezers or "blast cells" to rapidly freeze prior to shipping. A plan view of the plant's 20 independently operating blast cells is shown below in Figure 1.

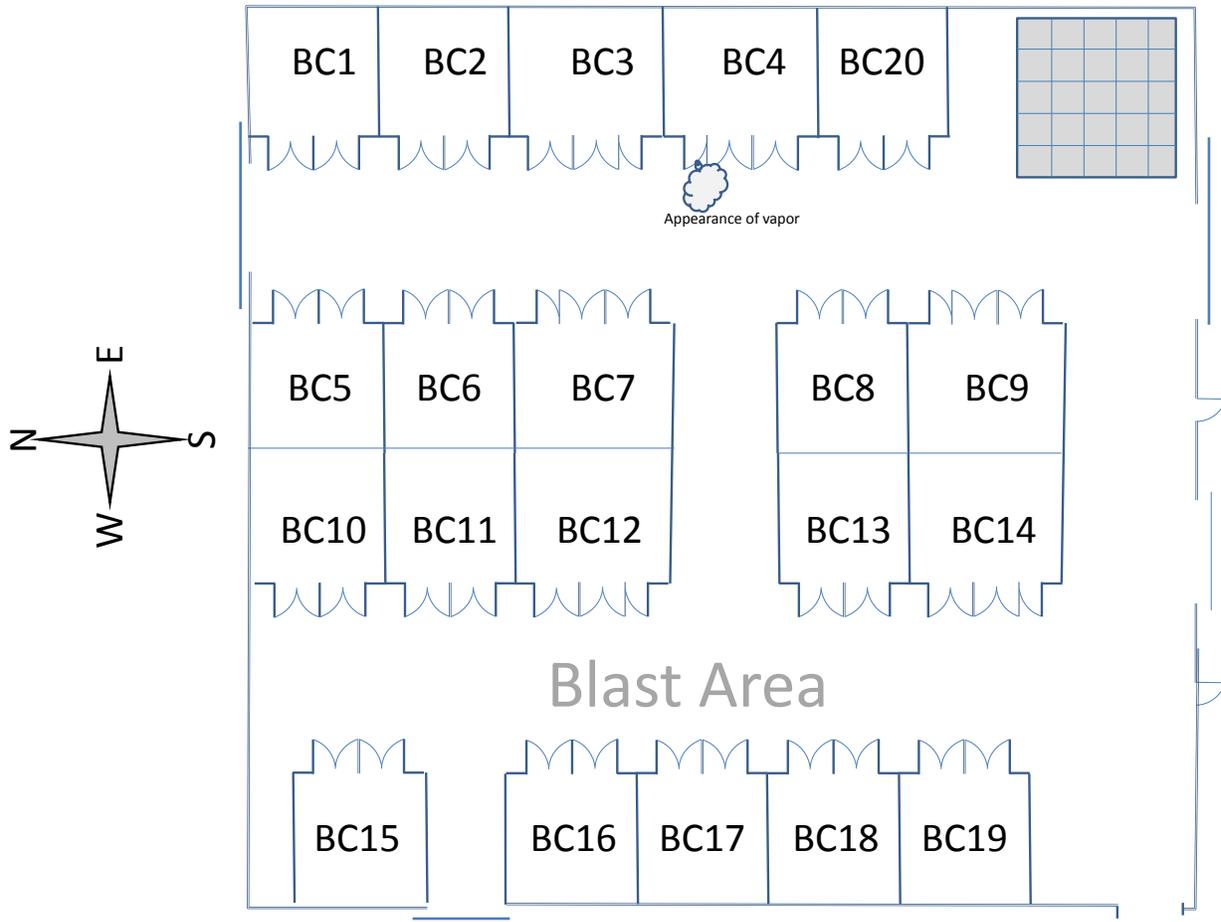


Figure 1: Plan view of plant blast cell area.

During normal operation, production personnel load or stack finished product into individual blast cells. Once loaded, the doors are closed and the room temperature is lowered to -35°F by an evaporator located within the cell to freeze product. The product will remain in the blast cell for a period that may be as short as 12 hours or as long as 36 or more hours.

During 2nd shift Jan 14, 2011, refrigeration personnel were called to investigate a noise and a "burnt smell" coming from Blast Cell #1.

Refrigeration Operator #2 discovered one of the four fan motors on the evaporator (see Figure 2) had burned out. Because each evaporator has only one electrical disconnect for the entire unit, individual fan motor fuses were sequentially pulled to electrically "disconnect" the failed motor while allowing the three remaining fans to operate so that the blast cell could remain in operation. Log entries did not accurately state what was done to the unit and why fuses were pulled.

During 3rd shift on early morning of January 15, 2011, production personnel notified refrigeration that "noise" was coming from Blast Cell #1. Refrigeration Operator #3 responded and found ice build-up on the shrouds surrounding the fans. The ice was removed and the unit returned to operation. Since the 2nd shift log was inaccurate, 3rd shift personnel were unaware of similar work being performed on the unit earlier in the day.

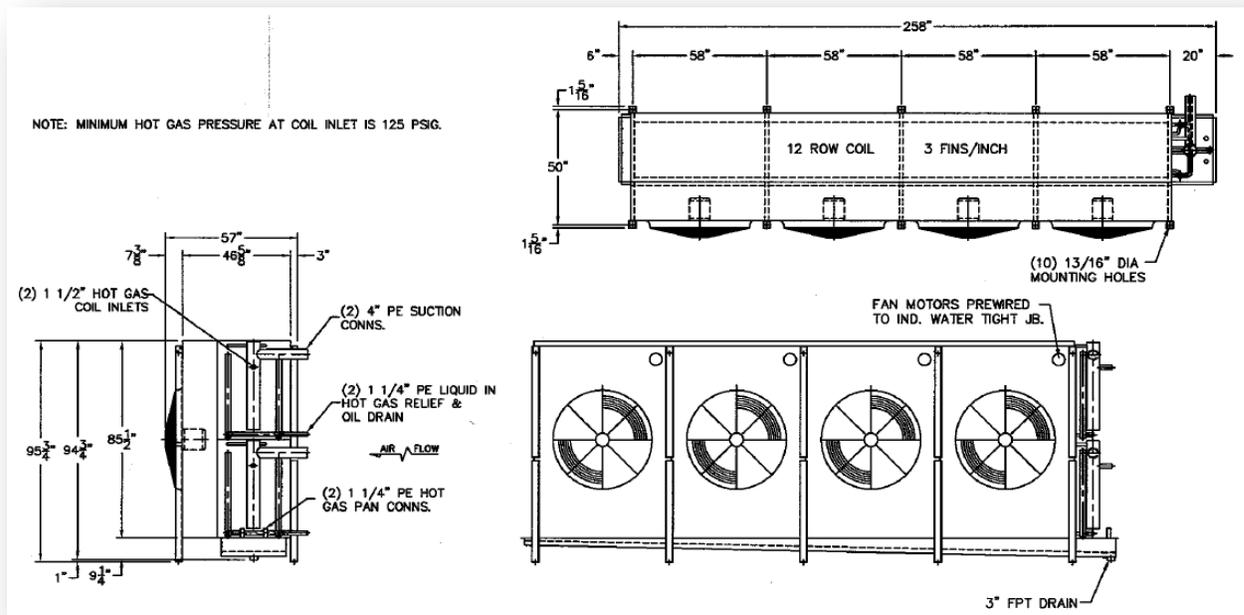


Figure 2: Blast Cell #1 evaporator details.

During 1st shift on the day of the incident (January 15, 2011), the blast cell production lead notified refrigeration personnel of noise still coming from Blast Cell #1. Two refrigeration operators responded to investigate the noise. One operator entered the motor control room to sequentially de-energize/energize individual fan motors on the unit while the second operator listened for the offending fan in the blast cell. The second operator reported the noise stopped when the unit's east fan motor was de-energized so they left that fuse pulled. Fuses were reinstalled on motor the failed

that 2nd shift had pulled. No visual inspection of the evaporator was performed at this time and 1st shift failed to make log entries recording what actions they took on Blast Cell #1.

Incident Occurs:

At approximately 7:15 pm on January 15, 2011, a forklift driver in the blast cell area notified the refrigeration lead of ammonia smell in the blast cell area. The 2nd shift refrigeration lead and the blast freezer supervisor entered the blast area and noticed what appeared to be "vapor" coming out the top of the north-end door of Blast Cell #4 (refer to the blast cell layout in Figure 1). The 2nd shift refrigeration lead shutdown the #4 Blast Cell evaporator by throwing the unit's disconnect in the MCC room. He also used the refrigeration system's control interface to de-energize the unit's hot gas solenoid, liquid feed solenoid, and evaporator fans.

The 2nd shift refrigeration lead returned to the blast area and saw what appeared to be a "fog" in the north east part of the blast area. He returned to the MCC room de-energized the hot gas solenoid, liquid solenoid, and evaporator fans for Blast Cells #1, #2, #3, and #20 (all five (5) blast cells located on the east end of the Blast Area). He also notified a refrigeration operator to turn off Blast Cells #1, #2, #3, #4, and #20 on the refrigeration control system. The 2nd shift refrigeration lead and an on-shift refrigeration operator then proceeded to the roof to manually isolate the refrigerant piping serving the Blast Cell #4 evaporator.

Hand-held ammonia detectors were used to measure blast area concentrations. Although readings were below 25 ppm outside of the Blast Area, the Freezer Supervisor and Production Team Lead made the decision to evacuate all plant employees to the north end of the plant as a precaution.

The previously notified refrigeration manager arrived at the plant at 8:00 pm and was briefed on the leak being informed that it had been contained and isolated. Continued surveillance of ammonia concentrations in the Blast Area showed readings in the 25-35 ppm range at the south end but rising to 80 ppm near Blast Cell #3. Believing the leak was isolated, steps to begin cleanup were initiated. Initial clean-up involved ventilating

the Blast Area by turning on plant exhaust fans and staging fans to move air outside to the Blast Area. The ammonia concentration in the Blast Area steadily decreased and sanitation was let back into those areas where the concentration was below 25 ppm.

At approximately 9:30 pm, the 2nd shift refrigeration lead and a newly arrived 3rd shift refrigeration operator proceeded to the roof to manually valve-out the liquid and hot gas supply to evaporator units in Blast Cells #1, #2, #3 and #20. The suction valves on these units were left open to "pump-out" any residual ammonia remaining in the units. Shortly thereafter, the HTRL 1 Recirculator for the high side evaporators high-levleled, causing the engine room to shut down. Pressures on the low-side began to rise as system pressures began to equalize. Refrigeration personnel were again notified that ammonia concentrations in the Blast Area were rising. Personnel were again evacuated from the Blast Area.

The engine room was restarted and the low-side once again brought into a vacuum. As the system continued to operate, it started to experience high head pressures. At the same time, a refrigeration operator monitoring the control room noticed the temperature probe in Blast Cell #1 was reading 160°F. At approximately 3:10 am on January 16, 2011, the refrigeration manager and a 3rd shift operator returned to the Blast Area with respirators donned and hand-held ammonia detectors. They opened the doors to Blast Cell #1 and observed liquid ammonia dripping onto pallets and the floor from the overhead evaporator in that blast cell. Refrigeration operators proceeded to the roof to isolate the suction isolation valves serving all the evaporators in east end of the Blast Area (Blast Cells #1, #2, #3, #4, and #20) which was not previously isolated. The leak was mitigated at approximately 3:30 am resulting in leak duration of approximately 8.25 hrs¹.

The total leak quantity was estimated at 4,074 lb_m.

¹Note: The initial external leak was isolated between 7:15 pm and 7:29 pm on 1/15/11. At approximately 9:30 pm an external leak on Blast Cell #1 reinitiated, caused by high level of HTRL1 high side Recirculator, allowing engine room to equalize above atmospheric pressure.

What was the leak source?

The leak source originated as the result of a loss of mechanical integrity of the **Blast Cell #1** evaporator coil caused by a fan blade on the unit piercing the coil. Figure 3 shows a close-up of one of the coil breaches (left photo) and other fan blade impact points on the coil face (right photo).

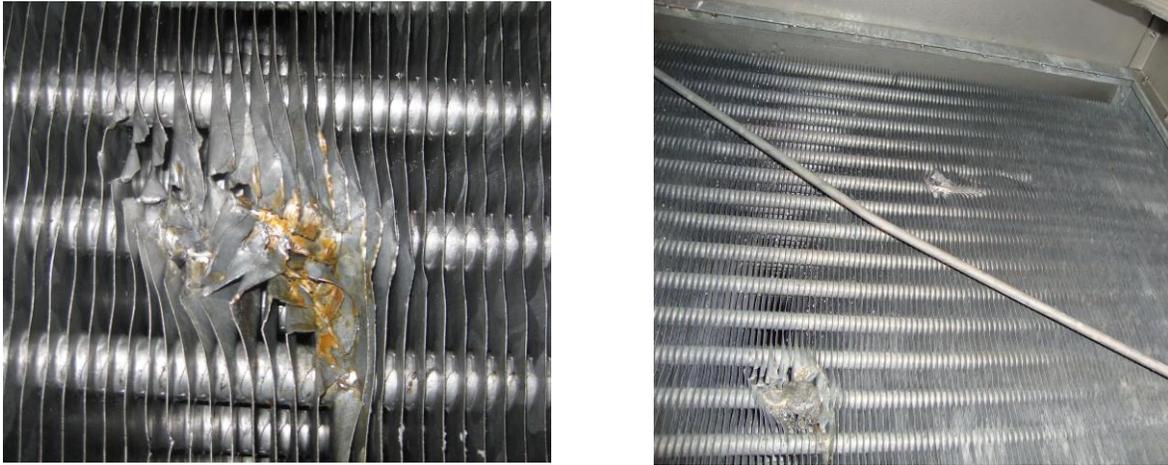


Figure 3: Fan blade impact points on Blast Cell #1 evaporator.

The fan blade was allowed access to the evaporator coil because the fan motor mounting bolts catastrophically failed as shown in Figure 4. It is likely that stray ice accumulation contributed to creating fan blade imbalance that was left uncorrected for a period of time. Chronic and excessive vibration caused the fan motor mounting bolts to progressively loosen. Once loose, vibration caused the fan motor mounting plate to progressive cut into the mounting bolts leading to their eventual failure. A post-mortem inspection of other fan motors on the blast cell area evaporators turned up a number of loose mounting bolts and several bolts that had loosened to the point of complete disengagement.



Figure 4: Fan motor mount failure on Blast Cell #1 evaporator.

Why was there confusion on finding the leak source?

Initially, plant personnel investigating the ammonia odor thought they saw what they believed to be ammonia vapor leaving through the upper part of the north-end door to Blast Cell #4. These identifying personnel were not close enough to the blast cell to correctly identify that the vapor being seen was actually leaving through the upper portion of the south-end door of Blast Cell #3.

If the leak originated in Blast Cell #1, how did the ammonia get from Blast Cell #1 to Blast Cell #3. The answer to that question lies in the piping arrangement for defrost condensate for evaporators in the blast cells. Figure 5 shows the layout of defrost condensate piping for each of the blast cells. The condensate pan drain lines for all blast evaporators are ganged together in three drain mains.

Unfortunately, drain connections from individual evaporators are not trapped. The lack of traps allowed ammonia vapor to migrate from Blast Cell #1 to Blast Cell #3 and all the other blast cells connected to that common condensate drain header. The preferred arrangement would be to have each condensate drain header individually trapped and properly heat traced.

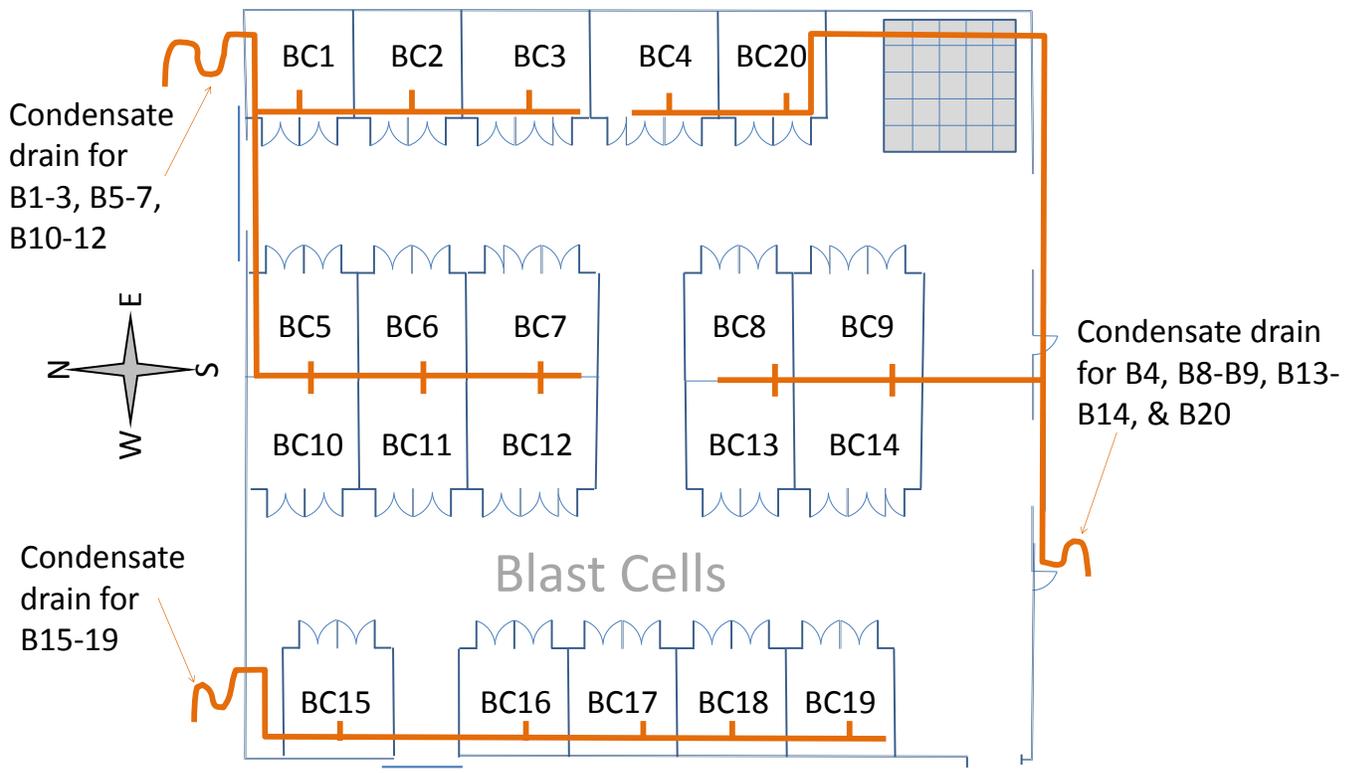


Figure 5: Defrost condensate drain lines for Blast Area.

What caused the temperature reading in Blast Cell #1 to reach 160°F?
 Through the course of the incident, the temperature in the blast cell was quite cold (-30°F or colder). The indicated temperature of 160°F was due to the high concentration of ammonia in the blast cell irreversibly damaging the sensor - in other words, it was a false reading.

What caused the recirculator serving the blast area to high level?
 The initial isolation of Blast Cells #1-#4 and #20 brought an excess amount of liquid back to the recirculator causing it to high level and shut the system down.

What caused high refrigeration system head pressures on the restart?
 Because the blast area evaporators operate in a vacuum, the loss of mechanical integrity of the Blast Cell #1 evaporator allowed air to leak into the system. With the suction open to Blast Cell #1 extended period of time, air infiltrated the refrigeration system and migrated to the high-side of the system causing a loss in condensing capacity which drove up system head pressure.

Impact of the Incident

Fortunately, **there were no on-site injuries or off-site consequences as a result of this incident.** However, there was a significant financial impact to the facility. At the time of the incident, all blast cells in the blast area were 100% occupied with product. Contamination claimed all product in the blast area resulting in a more than \$1MM of product loss. Production in the facility was halted for four days resulting in a business interruption in excess of \$7.5MM.

Estimates put the total loss of refrigerant due to the incident at 4,074 lbm of ammonia.

Incident Lesson's Learned

A number of "lesson's learned" were captured by the plant following the incident. Some of the key lesson's learned included:

- The evaporator locations, relative to the loading of products in each blast cell, prevented refrigeration operations staff from accessing the units to conduct inspections during operation.
- Logs and effective shift-to-shift communications are important. The plant recognized the existence of gaps in accurately documenting operational or maintenance issues associated with the evaporators across shifts. Symptoms of problems on the Blast Cell #1 evaporator when unconnected as various operators responded to individual problems but no or poor logs masked the significance of the problems from the refrigeration personnel.
- The plant recognized that the in-house Hazmat team was not adequately staffed or equipped for a 24x7 response.
- Not all lighting in the blast cells was functional. The lack of sufficient lighting diminished "situational awareness" during the leak investigation process.
- Mechanical integrity inspections (MII) for the blast cell evaporator units were inadequate and infrequent. Revised mechanical integrity (MI) procedures for these units need to be developed with expanded scope for inspection and increased frequency.

- Refrigeration personnel needed to have a better understanding of how the refrigeration system function can be adversely affected when decisions on a unit or subsystem level mitigation steps are taken. For example, refrigeration operators took mitigation steps that allowed the suction side of the system to remain open without knowing or realizing the precise location of breaches to the system's mechanical integrity. Ultimately, the low-side leak caused by damage to the evaporator in Blast Cell #1 allowed air to be drawn into the system which contributed to high operating system head pressures. Fortunately, the incident occurred during a period of cold ambient air temperatures which prevented the refrigeration system from shutting down on high head pressure.
- The plant did have a preventative maintenance program, procedures, and all records for the periodic inspection and testing of the ammonia detection system for the hard wired detectors used in the Blast Cell area. The plant could not verify that the hand-held detectors had current and accurate inspection/calibration records. If the hand-held detectors are incorporated into the plant's mechanical integrity, they will likely be inspected and calibrated according to the manufacturer's recommended intervals and practices. This would minimize the possibility of inconsistent readings from a fixed mount detection system and hand-held ammonia sensors.
- Recovery or disposal of ammonia-contaminated product in other blast cells was slowed because of local concentrations being above the short-term exposure limit. In addition, fork lift drivers were not trained in the use of or fitted with appropriate PPE that would have allowed them to remove product from blast cells. Some refrigeration personnel did not have forklift training.
- Procedures for dealing with large spills were not formally established. The methods and implementation plan for clean-up was successful but procedures need to be formalized, reviewed, and revised to ensure safe, effective mitigation, and decontamination.
- Handheld ammonia detectors used during the response did not have sufficient detection span or battery life. Additional handheld detectors had to be acquired during the course of the incident/mitigation process in order to quantify local airborne ammonia concentrations.

Recommendations

The recommendations presented in this case study emphasize steps that should be taken to prevent such incidents from occurring. Fewer recommendations are provided that address issues related to mitigating the release or the emergency response subsequent to the incident. The latter issues are important but what might be viewed as an inordinate emphasis on prevention here is intentional (keep the ammonia in the pipes and mitigation and emergency response become elementary).

- Replace existing evaporator fan motor mounting hardware with new mounting hardware that is vibration resistant and suitably rated for the operating temperature service. Specifically, consider installing lock nuts on the evaporator fan motor mounting bolts. In addition, ensure that all refrigeration personnel are trained in this change (MOC) including the proper use and installation of the new mounting hardware.
- Refine mechanical integrity inspections and tests for the blast cell air units to address the following:
 - Weekly²: Air units and the condensate drains examined weekly for excessive frost build-up. "Excessive" includes any additional frost build-up that may cause rotating mechanical equipment to excessively vibrate or frost/ice build-up on stationary surfaces that could collaterally affect rotating mechanical equipment on the unit. If excessive frost is found, the unit shall be defrosted as required and the operation of automatic defrost controls verified with appropriate adjustments made following the verification process.
 - Monthly²: Inspect all air units on a monthly basis for buildup of dirt or other contamination on evaporator tubes or finned surfaces. The units shall be cleaned as-required and visually inspected to ensure there are no signs of damage to the coil or finned surfaces.

On belt-drive evaporator fans, belt tension should be checked and adjusted per the manufacturer's instructions.

- Semi-annually: Fan blades, fan hubs, pulleys (if belt-driven), fan motors, and other structural elements of an air unit shall be inspected for visible cracks, corrosion,

²These requirements stem from Section 6.4.2.2 of IIAR Bulletin #110.

and tightness. The entire evaporator sequence of control shall be verified to coincide with the process safety information. Once reliability is demonstrated, this interval can reasonably extended to an annual basis.

- Refine mechanical integrity inspections and tests for valves associated with the blast cell air units to address the following:
 - Isolation valves (critical and non-critical) per the following table:

Interval	Inspection for manual actuation with exposed stem	Inspection for manual actuation with capped stem	Source
Monthly	<ul style="list-style-type: none"> • Leak check valve (packing, bonnet, pipe connection) and repair as-required. • Verify valve tag is in place. 	<ul style="list-style-type: none"> • Visual inspection for accumulation of ice that may interfere stem cap removal and valve actuation (closure). Clear ice as-needed. • Verify valve tag is in place. 	IIAR 110, 6.6.1
Annually ²⁵	<ul style="list-style-type: none"> • Inspect valve stem, clean, and lubricate. • For back-seated valves, move valve off of its back seat and verify its leak tightness. Repair as-required prior to back-seating. • If uninsulated, inspect valve body and connected piping for corrosion. Clean and paint/repair surfaces as-required. • For valves subjected to vibration or flow induced motion, inspect bonnets (both bolted and screwed) for leaks and repair as required. • Verify valve tag is in place. 	<ul style="list-style-type: none"> • Remove cap and inspect valve stem, clean, and lubricate as-required. Inspect stem cap gasket and vents. Replace cap gasket as-needed and clear vent prior to replacing cap. • For back-seated valves, move valve off of its back seat and verify its leak tightness. Repair as-required prior to back-seating. • Inspect valve body and connected piping for corrosion. Clean and paint/repair surfaces as-required. • For valves subjected to vibration, inspect bonnets (both bolted and screwed) for leaks and repair as required. • Verify valve tag is in place. 	IIAR 110, 6.6.1
Every 5 years	<ul style="list-style-type: none"> • Fully actuate the valve and prove it stops flow by utilizing acoustic (e.g. electronic stethoscope) or ultrasonic inspection method. • Complete protocol for items included in the annual inspection. • Cross-reference valve tag with other process safety information e.g. P&ID, SOPs, etc. 	<ul style="list-style-type: none"> • Fully actuate the valve and prove it stops flow by utilizing acoustic (e.g. electronic stethoscope) or ultrasonic inspection method. • Complete protocol for items included in the annual inspection. • Cross-reference valve tag with other process safety information e.g. P&ID, SOPs, etc. 	IIAR 110, 6.6.1

²⁵ -For outdoor inspection of manual actuation valves with exposed stem, this interval should be semiannually (IIAR Bulletin 110).

- Refine mechanical integrity inspections, tests, and calibrations for hand-held ammonia detectors. Ensure that the inspections,

tests, and calibrations of the hand-held detectors are properly documented.

- Consider installing ammonia sensors in each of the 20 blast cells. The sensors should trigger alarms and visual beacons in the blast area to notify personnel in the area as well as a centralized command (such as plant security). Consider adding controls to allow the sensor to close and interrupt the liquid supply and hot gas supplied to the units to mitigate refrigerant loss. The inspections, tests, and calibration of these safety systems must be integrated into the plant's mechanical integrity program.
- Conduct a PHA for the entire blast area and develop appropriate recommendations that address facility siting of covered process equipment in that area as well as human factors. Ensure that the PHA considers:
 - whether or not piping, valves, and other blast cell components are fully accessible with or without various levels of PPE donned,
 - potential modifications to the blast cells that would permit operator access for air unit inspection with full product load in place.
- Install a "ShockWatch³[®]" or similar sort of devices on each blast cell evaporator. This device senses excessive vibration and triggers an alarm notification, automatic shutdown of the evaporator fan, and automatic closure of refrigerant supply valves (liquid feed, hot gas).
- Re-pipe the defrost condensate drain lines so that each individual evaporator is properly trapped. This eliminates the condensate drain path as a conduit for cross-contaminated blast cells containing a leak with those that are leak-free.
- Equip all refrigeration personnel with the appropriate training and credentialing to drive fork trucks in the blast area.
- Verify accuracy and completeness of mass energy balances for all blast area equipment (evaporators, piping, vessels, compressors, etc.).

³ ShockWatch[®] is a registered trademark of Shockwatch, Inc., of the United States of America.