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Hazardous Ammonia Release at Cuisine Solutions, Inc. Facility

Sterling, Virginia | *Incident Date: July 31, 2024* | **No. 2024-03-I-VA**

Investigation Report

Published: September 2025

SAFETY ISSUES:

- **Two-phase Atmospheric Relief**
- **Discharging to a Safe Location**
- **Emergency Preparedness**

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ABBREVIATIONS

AHJ	Authority Having Jurisdiction
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTI	Ammonia Safety & Training Institute
CCPS	Center for Chemical Process Safety
CFR	Code of Federal Regulations
CSB	U.S. Chemical Safety and Hazard Investigation Board
EAP	Emergency Action Plan
EPA	Environmental Protection Agency
EPCS	Emergency Pressure Control System
ERPG	Emergency Response Planning Guideline
HAZMAT	Hazardous Materials
HMI	Human Machine Interface
HPR	High-Pressure Receiver
HTA	High-Temperature Accumulator
HVAC	Heating, Ventilation, and Air Conditioning
IAD	Washington Dulles International Airport
ICC	International Code Council
IDLH	Immediately Dangerous to Life or Health
IIAR	International Institute of All-Natural Refrigeration

IMC	International Mechanical Code
IRC	Industrial Refrigeration Consortium
MAWP	Maximum Allowable Working Pressure
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PHAST	Process Hazards Analysis Software Tool
PPE	Personal Protective Equipment
ppm	Parts per Million
PPMV	Parts per Million by Volume
PRD	Pressure Relief Device
PRV	Pressure Relief Valve
psig	Pounds per Square Inch gauge
PSM	Process Safety Management
RAGAGEP	Recognized and Generally Accepted Good Engineering Practice
RMP	Risk Management Program
SDS	Safety Data Sheet
UMC	Uniform Mechanical Code

EXECUTIVE SUMMARY

On July 31, 2024, at approximately 8:20 p.m., anhydrous ammonia, a toxic substance, was accidentally released at the Cuisine Solutions, Inc. ("Cuisine Solutions") food processing facility in Sterling, Virginia, when an emergency pressure relief valve discharged to the atmosphere. The released ammonia formed a toxic cloud. As personnel evacuated from the facility, many inhaled ammonia vapor and were injured, four of them seriously.

The Cuisine Solutions Sterling plant produces cooked packaged food products for hotels, airlines, and restaurants, as well as other industries and consumers [1, 2]. The plant's food processing and storage facilities require an industrial-scale refrigeration process, which uses ammonia as the refrigerant. The refrigeration process chills the water for the food production lines and maintains refrigerator and freezer temperatures for food storage.

Sometime during the evening of July 31, 2024, a refrigeration process upset likely began in one of the heat exchange processes, ultimately leading to overpressure[a] in a vessel called the Heat Exchanger 5 Surge Drum at approximately 8:20 p.m. As a result, the emergency pressure relief valve on the vessel opened, which discharged ammonia to the atmosphere. Because the discharged ammonia contained a high level of liquid, some of the ammonia rapidly slumped to ground level. Shortly thereafter, the production manager called for a site evacuation. However, throughout the incident none of the alarms from the ammonia detection sensor system inside the production areas of the plant activated, and no sitewide evacuation alarm sounded. Moreover, during the incident no one used the emergency shutdown buttons that could have limited the ammonia release.

During the evacuation, some personnel inhaled ammonia vapor and were injured. When emergency responders arrived at the scene they found more than ten unconscious individuals. Thirty-three workers were transported to area hospitals for treatment. Four of them were admitted to the hospitals, including one who was placed in intensive care.

At the time of the incident, the Cuisine Solutions Sterling plant employed approximately 716 employees and contractors, and 286 were onsite. The CSB estimates the release at approximately 275 pounds of anhydrous ammonia.[b] Cuisine Solutions estimated the property damage, including loss of use, to be approximately $3 million. One of the food production lines was shut down for approximately 16 days, and another production line was shut down for approximately 38 days.

SAFETY ISSUES

The CSB's investigation identified the safety issues below.

- **Two-phase Atmospheric Relief.** The Cuisine Solutions Sterling plant ammonia refrigeration system had emergency pressure relief systems that discharged ammonia to the atmosphere. The relief to the atmosphere likely resulted in immediately dangerous to life or health (IDLH) ammonia concentrations

[a] An overpressure is a condition where the maximum allowable pressure inside a vessel is exceeded [34, p. 14].

[b] This release represents approximately 1.3 weight percent of the Sterling plant's total anhydrous ammonia inventory. The Reportable Quantity of anhydrous ammonia is 100 pounds, both to the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA).

at ground level, based on relief scenarios modeled by the CSB involving liquid aerosols or two-phase (liquid and vapor) flow out of the atmospheric relief discharge. In modeled overpressure relief situations involving liquid aerosols or two-phase flow out of the common relief header discharge, the result was ammonia concentrations at ground level considered to be IDLH (**Section 4.1**).

- **Discharging to a Safe Location.** A fundamental design principle for an emergency pressure relief system is to ensure that the system discharges to a safe location and no people are harmed. During this incident, the atmospheric discharge was vented next to the employee parking lot and the building, which restricted the ability to safely evacuate, caused harm to people, and affected a nearby public receptor, the Postal Inspection Service across the road from the Sterling site (**Section 4.2**).

- **Emergency Preparedness.** On the night of the incident, the onsite personnel generally executed the site's Emergency Action Plan (EAP) as written. However, the CSB identified several gaps in the EAP and in the site's overall emergency preparedness, including: not accounting for wind direction; not differentiating between indoor and outdoor ammonia releases; not having written emergency shutdown procedures employees could follow before or during evacuation; ineffective drills for ammonia releases; a lack of effective communication during a release including that no evacuation alarm sounded during the incident; and ineffective planning and training on the use of the refrigeration system emergency shutdown function. These gaps led to a delayed and disorganized evacuation, which likely increased the risk of ammonia inhalation by personnel at the plant (**Section 4.3**).

CAUSE

The CSB determined that the cause of the incident was an overpressure in a vessel that released a toxic ammonia cloud through an emergency pressure relief valve that opened near the employee parking lot. The ammonia cloud contained a significant liquid component, which caused much of it to rapidly drop to ground level, exposing workers while they evacuated.

Contributing to the incident was a failure to discharge this emergency pressure relief valve to a safe location and a lack of engineering or administrative controls, such as an automated emergency refrigeration system shutdown, that could have minimized liquid or aerosol in the ammonia release.

The Cuisine Solutions Sterling plant's insufficient emergency preparedness, including the site Emergency Action Plan which did not ensure workers could safely evacuate in the event of an outdoor ammonia release, a lack of effective drills, and a lack of effective emergency shutdown, contributed to the severity of the incident.

Recommendations

To International Institute of All-Natural Refrigeration (IIAR)

2024-03-I-VA-R1

Update ANSI/IIAR 2[a] to include guidance for preventing or mitigating liquid or two-phase atmospheric discharges from emergency pressure relief systems, such as the guidance in API Standard 521, *Pressure-relieving and Depressuring Systems*. At a minimum, the guidance should:

a. Identify at-risk scenarios such as horizontal surge vessels and other vessels containing saturated liquid with little vapor space;

b. Address design considerations and controls to reduce the likelihood of identified scenarios leading to overpressure or equipment failure and ensure vapor-liquid disengagement (the separation of vapor from liquid) during pressure relief for identified scenarios; and

c. Require mitigative safeguards in cases where vapor-liquid disengagement during pressure relief cannot be reliably ensured. This should also include alternative disposal systems where applicable.

2024-03-I-VA-R2

Update ANSI/IIAR 2 to include a requirement to assess whether emergency pressure relief devices discharge to a safe location, such as with a dispersion analysis.

To Cuisine Solutions, Inc., Sterling Site

2024-03-I-VA-R3

Reduce the likelihood or mitigate the consequences of liquid or two-phase atmospheric discharges from the ammonia refrigeration emergency pressure relief system at the Sterling plant. At a minimum:

a. Identify liquid or two-phase release scenarios, particularly for horizontal surge drums and other vessels containing saturated liquid with little vapor space;

b. Implement engineering controls to reduce the likelihood of high liquid level, overfill, or boiling overpressure scenarios; and

c. Implement engineering controls to mitigate the consequences of these scenarios where their likelihood cannot be acceptably reduced, such as through emergency pressure control systems, atmospheric knockout drums, or automatic shutdown systems.

d. Contract a competent third party to audit the pressure relief systems. The audit should ensure that (i) all relevant relief scenarios have been identified, (ii) preventive and mitigative engineering controls

[a] The IIAR has issued a series of standards and guidelines, some of which have been adopted by the American National Standards Institute (ANSI), and one of which is ANSI/IIAR 2 [13, p. v].

adequately address the hazards, and (iii) engineering controls are maintained in such a way that they function properly when required.

2024-03-I-VA-R4

Implement an electronic process data historian and management system to ensure that critical process parameters are collected, tracked, and stored. The system should be available to refrigeration technicians so that they can monitor the refrigeration system and respond to and investigate process upsets.

2024-03-I-VA-R5

Update the Cuisine Solutions Sterling site's Emergency Action Plan using guidance such as the IIAR's *Critical Task Guidance for Ammonia Refrigeration System Emergency Planning*. At a minimum, the updated plan should:

a. Address indoor and outdoor ammonia releases separately, including the distinct alarms and responses to them;

b. Clearly specify appropriate evacuation routes and muster points, including alternates;

c. Provide guidance for using windsocks[a] to remain upwind of a release during evacuation;

d. Implement shelter-in-place strategies, emergency protective equipment, and emergency shutdowns, as appropriate; and

e. Include requirements to conduct annual ammonia release drills that include all onsite personnel (including corporate employees). The annual drills should include separate indoor and outdoor ammonia release scenarios and address the use of windsocks to assist with determining evacuation routes, alternate evacuation routes, muster points, and consideration for the decision to shelter-in-place. Additionally, the drills should exercise each evacuation alarm, emergency protective equipment, and emergency shutdowns, where appropriate.

2024-03-I-VA-R6

Add an alarm or alarms specific to ammonia releases, so that workers can properly respond to a release. The alarm response should be documented in the updated Emergency Action Plan, and may include multiple distinct alarms and responses, such as one for shelter-in-place and one for evacuation.

[a] A windsock is "a tube of cloth fastened at one end to a pole that shows the direction of the wind…" [53].

1 BACKGROUND

1.1 CUISINE SOLUTIONS

Cuisine Solutions, Inc. ("Cuisine Solutions") is a privately held U.S. corporation based in Sterling, Virginia. In addition to its Sterling, Virginia, plant where the incident occurred, the company also has plants in San Antonio, Texas, and Alexandria, Virginia. Cuisine Solutions' corporate headquarters are also located within the same Sterling, Virginia, site [3], (the "Sterling site")[a] as shown in **Figure 1**. The corporate offices include a test kitchen and a cooking school, which added to the number of personnel onsite, separately from the plant population.

The Cuisine Solutions Sterling plant (the "Sterling plant")[b] produces cooked, packaged food products for hotels, airlines, and restaurants, as well as other industries and consumers [1, 2]. The cooking method used at the Sterling plant is called "sous vide," which is French for "under-vacuum" [1]. During this industrial, large-scale cooking process, food servings are placed in a vacuum-sealed pouch and slow-cooked in a water bath at a low cooking temperature [1].

Cuisine Solutions began operations at the Sterling, Virginia, plant in 2013 and expanded its production lines significantly in 2017. This expansion also required an increase in refrigeration capacity. In 2013, the plant's ammonia inventory was approximately 13,000 pounds. It increased to nearly 21,000 pounds in 2017, which was still the quantity at the time of the incident. The July 31, 2024 anhydrous ammonia release occurred in an area known as Tank Farm 5, which was added in 2017. The orange pin in **Figure 1** shows the approximate location of the July 2024 release.

[a] Throughout this report, the "Sterling site," or simply "the site," refers to the location as a whole, including the plant and corporate offices, etc.

[b] Throughout this report, the "Sterling plant" refers to the manufacturing plant.

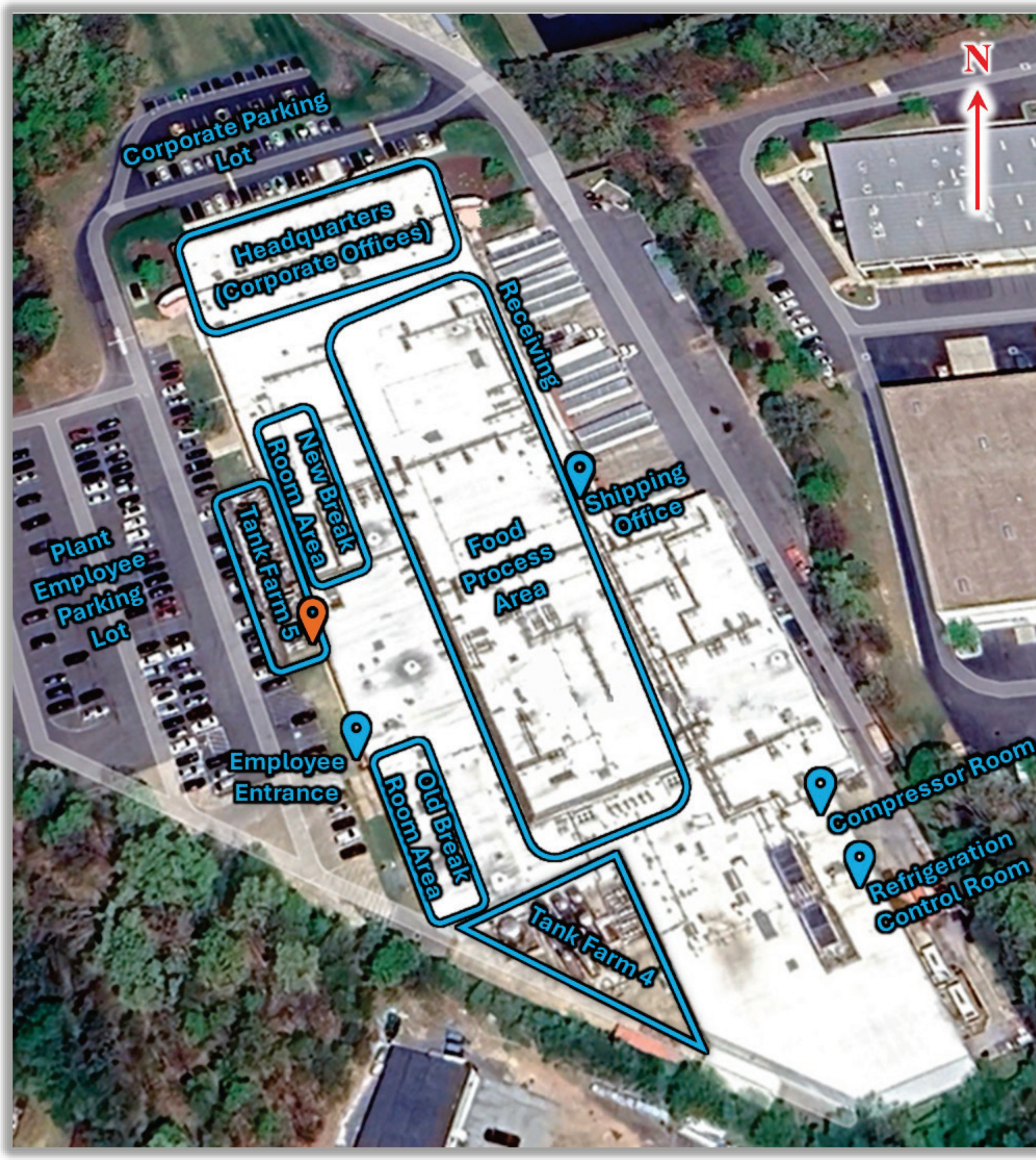

Figure 1: An overhead view of the Sterling site shows the location of the release (orange pin). (Credit: Google Earth, annotated by CSB)

The Sterling plant's food processing and storage facilities require industrial refrigeration, which uses ammonia as the refrigerant. The refrigeration process chills the water for the sous vide production lines and maintains refrigerators and freezers for food storage. Most of the refrigeration equipment and most of the ammonia storage were in the compressor room (**Figure 1**). Next to the compressor room, the refrigeration control room contained a Human Machine Interface (HMI) where refrigeration personnel could monitor and make adjustments to the refrigeration process and respond to refrigeration system alarms.

At the time of the incident, the Sterling plant employed approximately 716 workers in total.[a] Employees at the Sterling plant worked one of three 8-hour shifts.[b] At the time of the incident, 286 workers were in the plant, working the second shift.

1.2 Sterling Plant Organization

Figure 2 shows part of the Sterling plant's organization chart, which includes the second shift's production, maintenance, and refrigeration personnel.

During the second shift, the maintenance group primarily supported the production group in the Food Process Area (**Figure 1**), while the refrigeration technician was responsible for the refrigeration system, including the Tank Farms, Compressor Room, and Refrigeration Control Room (**Figure 1**). However, it was common practice for the maintenance group to collaborate with the refrigeration technician when necessary. One maintenance technician on the second shift, with some training in refrigeration, served as backup to the refrigeration technician when needed, such as during meal breaks.

The refrigeration technician reported to the refrigeration manager. The refrigeration manager typically worked hours overlapping first and second shifts.

[a] Throughout this report, "workers" means employees and contract workers collectively. A large percentage of the food production line workers were contract employees.

[b] First shift: 6 a.m. – 2 p.m., Second shift: 2 p.m. – 10 p.m., Third shift: 10 p.m. – 6 a.m.

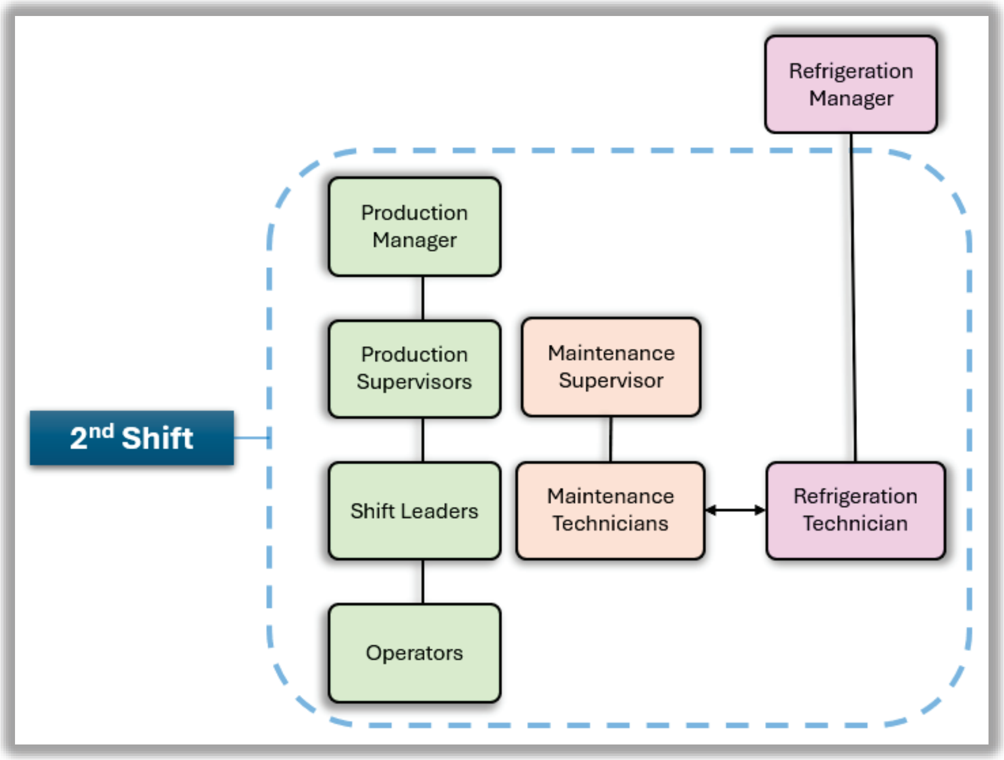

Figure 2: Partial Sterling plant organization chart describes the plant's second shift (in box) production (green), maintenance (orange), and refrigeration (purple) groups. (Credit: CSB)

1.3 Ammonia Properties

Anhydrous ammonia, which is ammonia without water, is essentially pure (> 99 weight percent) NH_3 [4]. It is toxic when inhaled, with a concentration immediately dangerous to life or health (IDLH) of 300 parts per million (ppm) or greater [5, 6, pp. 4, 5]. Exposure to ammonia below 300 ppm can cause headaches, nausea, vomiting, coughing, wheezing, and irritation to the nose, mouth, and throat [7, p. 1.2]. The odor threshold for anhydrous ammonia is 5 to 50 ppm [4].

Ammonia's natural refrigerating properties make it highly suitable for refrigeration applications. It boils at -28 degrees Fahrenheit (°F) at atmospheric pressure and is stored in pressurized containers to prevent rapid evaporation [4]. When the pressure is reduced, liquid ammonia evaporates while absorbing heat from warmer surroundings, such as air or water. This heat absorption lowers the temperature of the surrounding environment, making ammonia useful for cooling applications [4].[a]

An anhydrous ammonia release can absorb moisture from the atmosphere and form a dense, visible white cloud that may remain close to the ground [7, p. 1.2]. A toxic ammonia cloud may not be visible without sufficient atmospheric moisture condensing to make a cloud visible.

[a] Ammonia is also non-ozone depleting and has minimal global warming potential [28, p. 417].

When mixed with air, ammonia has a lower flammability limit of 16 weight percent in air and an upper flammability limit of 25 weight percent in air [4]. This means that ammonia vapor is combustible if its concentration in air is within this range. An ammonia Safety Data Sheet notes that "outdoors, ammonia is not generally a fire hazard" [6, pp. 3, 5].

1.4 Process Description

In the sous vide cooking process, food is vacuum-sealed in a pouch and slow-cooked in a water bath using a predetermined recipe. Once cooked as desired, the cooking process is stopped using a chilled water bath. After the food is cooled, it is stored in freezers and prepared for transport to customers. At the Sterling plant, the ammonia refrigeration system regulated the chilled water temperatures and the required temperatures for storage freezers and other cooled areas of the plant [8, pp. 549-552].

1.4.1 Ammonia Refrigeration System at Cuisine Solutions

Like many companies in the food industry, Cuisine Solutions uses an ammonia refrigeration system at the Sterling plant to cool the chilled water system, freezers, and chillers [8, pp. 549-552]. To supply all the plant's refrigeration needs, Cuisine Solutions operates a refrigeration process at three different pressures, which provides ammonia at three different temperatures: the high-pressure loop at 30 °F, the intermediate pressure loop at 12 °F, and the low-pressure loop at -48 °F. A simplified schematic of the refrigeration process high-pressure loop is shown in **Figure 3**.

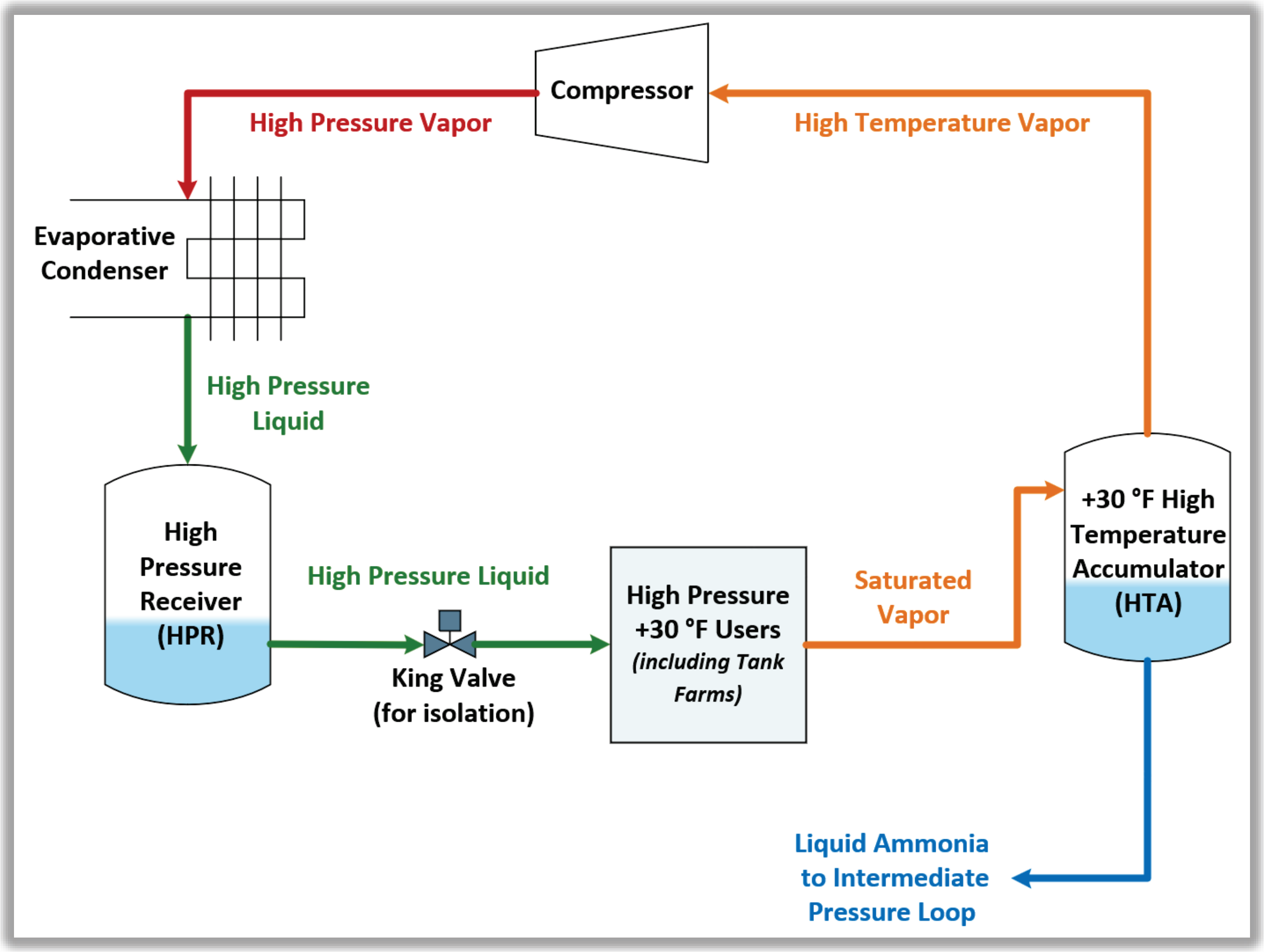

Figure 3: Simplified description of the Sterling plant ammonia refrigeration cycle. (Credit: CSB)

Ammonia liquid is stored at high pressure in the high-pressure receiver (HPR). The HPR also can contain the system volume if needed in an emergency. Warm, high-pressure ammonia liquid exits the HPR and passes through the king valve (also referred to as the shut-off valve).[a] The primary function of the king valve is to stop the flow of ammonia and isolate sections of the refrigeration system in an emergency.

After passing through the king valve, part of the warm, high-pressure liquid is directed to various high-pressure ammonia users at +30°F, including in the Tank Farm 5 area. The ammonia liquid reduces pressure as it enters the cooling equipment in the loop, which also drops the temperature. The ammonia evaporates in the equipment, and the resulting 30 °F saturated vapor[b] enters the high-temperature accumulator (HTA). Liquid ammonia feeds the intermediate pressure loop while the remaining high-temperature ammonia vapor flows to the compressors.

[a] According to the International Institute of All-Natural Refrigeration, "The main system shut-off valve is frequently referred to as the king valve. It is used to stop or start the flow of ammonia liquid from the receiver into the entire system. King valves are generally located on the liquid outlet side of the high-pressure receiver" [54, p. 4].

[b] Throughout this report, "saturated vapor" or "saturated liquid" refers to vapor and liquid at thermodynamic equilibrium with each other. In ammonia refrigeration systems, it is not unusual for saturated vapor to contain some amount of liquid and vice versa [29, p. 3.4].

Once compressed, the high-pressure vapor is condensed back into warm, high-pressure ammonia liquid. The liquid ammonia is returned to the HPR, and the refrigeration cycle begins again.

1.4.2 Tank Farm 5 Heat Exchangers

In 2017, Cuisine Solutions expanded its sous vide processing at the Sterling plant, including its ammonia refrigeration system. Tank Farm 5 and some food processing areas were constructed as part of this expansion (**Figure 1**).

Tank Farm 5 contained chilled water storage tanks, and ammonia refrigeration system surge drums and heat exchangers (**Figure 4**). As described in **Section 1.4.1**, part of the warm, high-pressure liquid from the HPR at approximately 80 °F and 150 pounds per square inch gauge (psig) was directed to various high-pressure ammonia users, including the surge drums. At the surge drums, the ammonia pressure dropped to approximately 40 psig across the liquid inlet valves, which also dropped the ammonia temperature to approximately 30 °F. The surge drums flooded the heat exchangers with 30 °F saturated liquid ammonia to promote heat transfer between the liquid ammonia and the water stream, which evaporated the ammonia. The saturated ammonia vapor was then returned to the HTA in the compressor room (**Figure 5**). Each chilled water tank was controlled to a different water temperature to meet food processing needs. Tank Farm 4, a similar but separate arrangement to Tank Farm 5, was located on the south end of the Cuisine Solutions site.

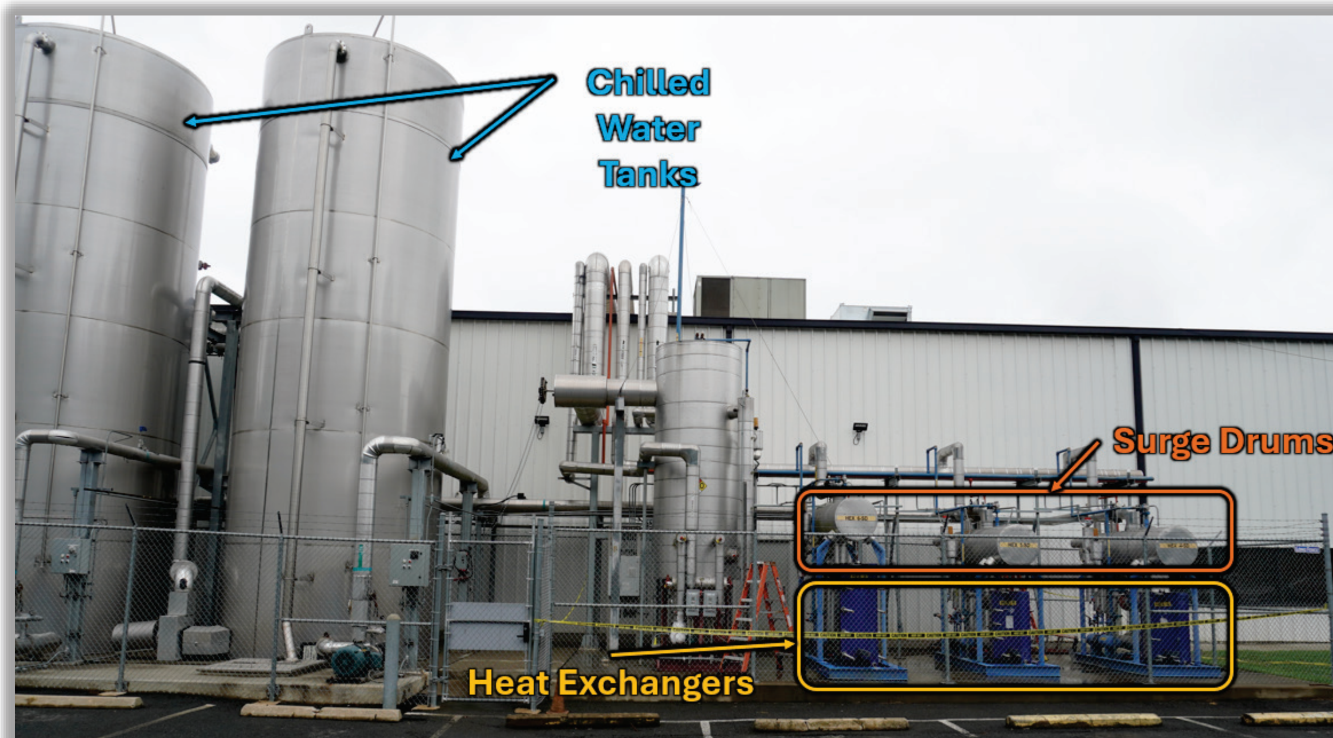

Figure 4: The chilled water tanks, surge drums, and heat exchangers in Tank Farm 5. (Credit: CSB)

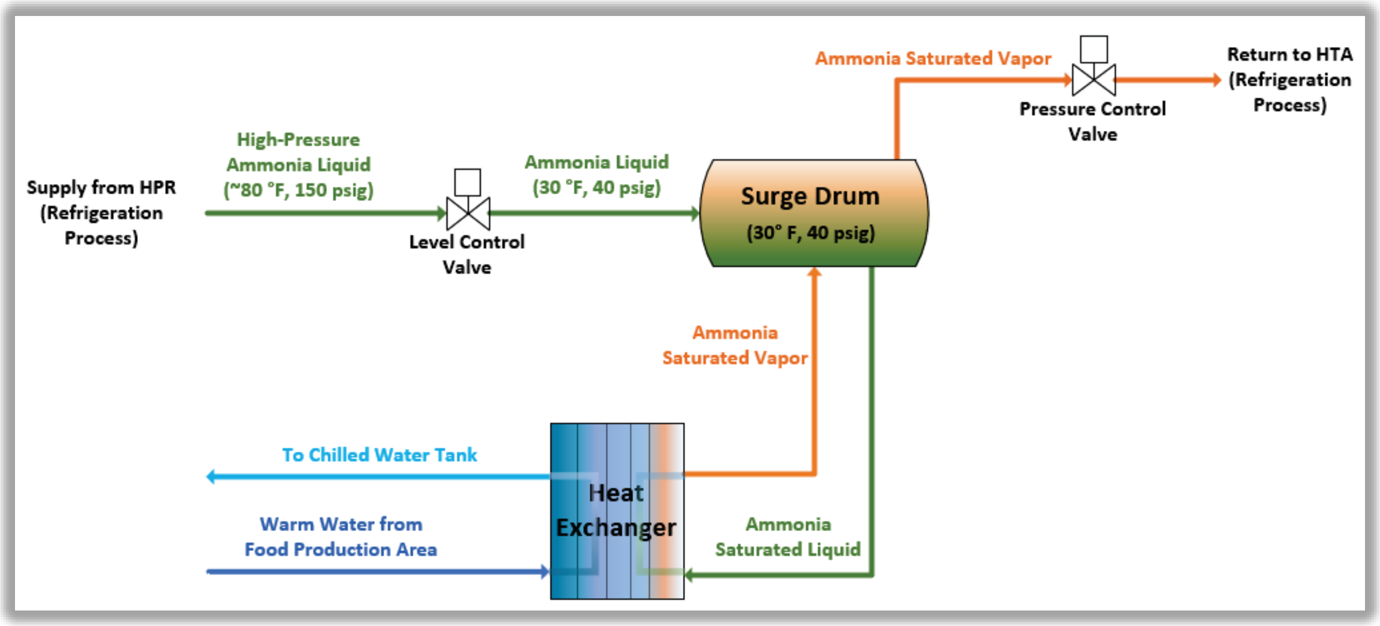

Figure 5: Simplified process diagram of Heat Exchanger 5 and its Surge Drum in Tank Farm 5. (Credit: CSB)

1.4.3 Emergency Pressure Relief Valves

The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code requires pressure vessels to have emergency pressure relief valves that are designed to open at or below a maximum allowable working pressure (MAWP)[a] to prevent equipment damage and catastrophic failures [9, p. 94]. Each pressure vessel in Tank Farm 5 included at least one emergency pressure relief valve.[b] The relief system assembly used in the surge drums included a three-way selector valve[c] with two emergency pressure relief valves attached (**Figure 6**). This type of arrangement ensured that one emergency pressure relief valve was in service, while the standby emergency pressure relief valve was isolated until the three-way selector valve was switched. The emergency pressure relief valves discharged to a common relief header, which discharged to the atmosphere, as shown in **Figure 7** below.

[a] ASME Boiler and Pressure Vessel Code, Section VIII defines MAWP as "the maximum pressure permissible at the top of the vessel in its normal operating position at the designated coincident temperature specified for that pressure" [52, p. 78].

[b] The vessels in Tank Farm 5 that are considered pressure vessels are: Heat Exchanger 4, Surge Drum 4, Surge Drum 4 Oil Pot, Heat Exchanger 5, Surge Drum 5, Surge Drum 5 Oil Pot, Heat Exchanger 6, Surge Drum 6, Surge Drum 6 Oil Pot, Low Temperature Receiver 2, and Low Temperature Receiver 2 Oil Pot.

[c] The three-way selector valve, or changeover valve, is "a three-way stop (or diverter) valve with one inlet port and two outlet ports designed to isolate either one of the two outlet ports from the inlet port, but not both simultaneously during any mode of operation" [46, p. 95].

Figure 6: Emergency pressure relief valve assembly for a surge drum in Tank Farm 5, including two emergency pressure relief valves (green) and the three-way selector valve (orange). (Credit: CSB)

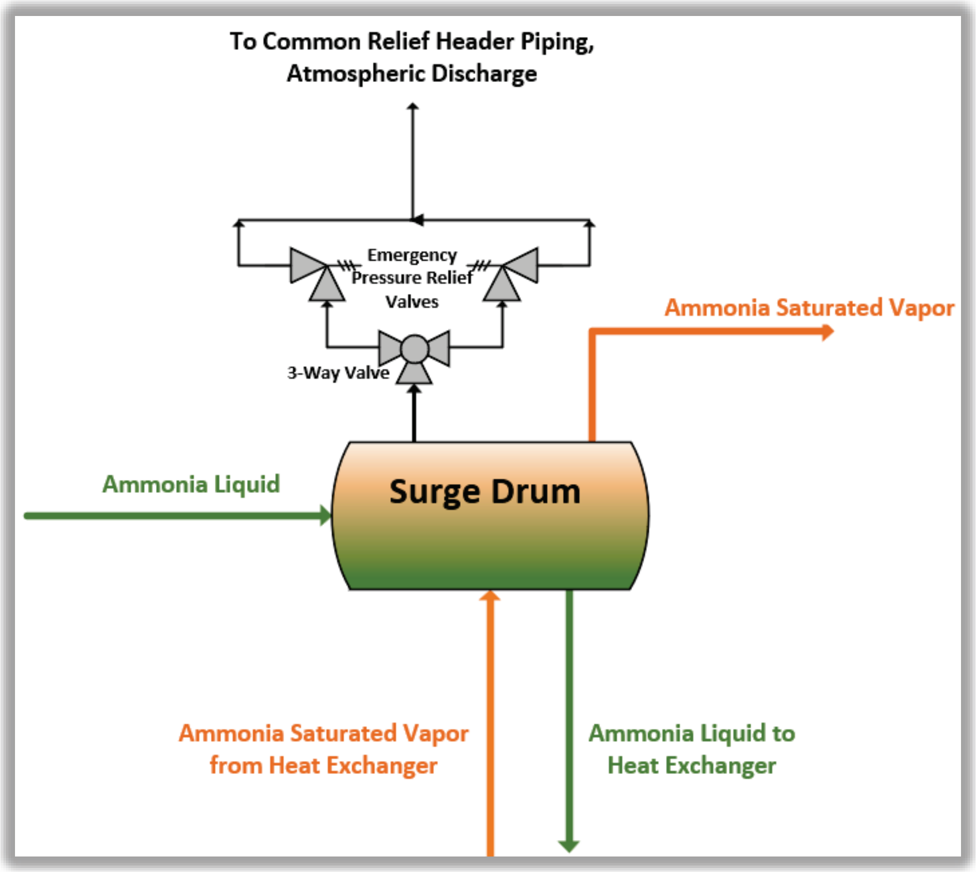

Figure 7: Emergency pressure relief valve assembly on a surge drum. (Credit: CSB)

A total of 18 emergency pressure relief valves were installed throughout Tank Farm 5. These emergency pressure relief valves protected the associated equipment from excess pressure conditions. When any emergency pressure relief valve is activated, it would discharge ammonia into the atmosphere through a tee diffuser (**Figure 8**) at the end of the common relief header.

The common relief header also included a sensor to detect ammonia inside the piping. This would alert refrigeration technicians when an emergency pressure relief valve was leaking and required maintenance or had been activated in an overpressure event.

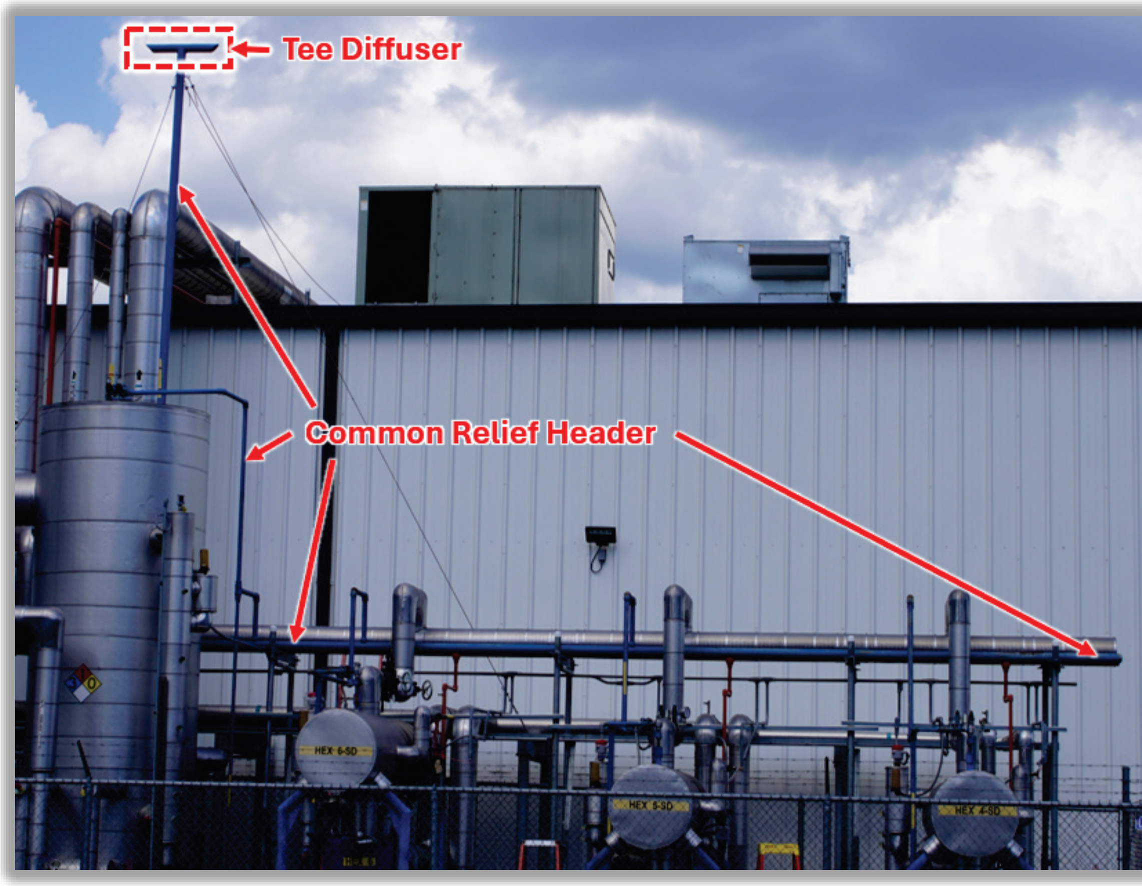

Figure 8: The ammonia common relief header in Tank Farm 5 with tee diffuser discharge to atmosphere. The common relief header piping is painted blue. (Credit: CSB)

1.5 Federal Safety Regulations

Cuisine Solutions records show that its Sterling plant anhydrous ammonia refrigeration system, which contained up to 21,000 pounds of anhydrous ammonia, was subject to the Occupational Safety and Health Administration (OSHA)'s Process Safety Management (PSM) standard[a] and the Environmental Protection Agency (EPA)'s Risk Management Program (RMP) rule.[b]

1.5.1 OSHA Process Safety Management Standard

OSHA's PSM standard was implemented on May 26, 1992. According to OSHA, the PSM standard:

> [E]stablishes procedures for process safety management that will protect employees by preventing or minimizing the consequences of chemical accidents involving highly hazardous chemicals. Employees have been and continue to be

[a] 29 C.F.R. § 1910.119, Appendix A
[b] 40 C.F.R. § 68.130

> exposed to the hazards of toxicity, fires, and explosions from catastrophic releases of highly hazardous chemicals in their workplaces. The requirements in this standard are intended to eliminate or mitigate the consequences of such releases [10].

The Sterling plant ammonia inventory, at approximately 21,000 pounds, was above the 10,000-pound threshold quantity per 29 C.F.R. 1910.119—Appendix A—List of Highly Hazardous Substances. Therefore, the ammonia refrigeration process was subject to compliance with OSHA's PSM requirements for handling ammonia and preventing and minimizing ammonia releases.

OSHA cited Cuisine Solutions for ten violations of the PSM standard and other OSHA requirements and fined the company $131,535 in connection with the July 31, 2024 incident.[a]

1.5.2 EPA Risk Management Program Rule

The Sterling plant's ammonia inventory was above the 10,000-pound threshold prescribed in the EPA's RMP rule.[b] The RMP rule requires the owner or operator of a stationary source with an inventory greater than the threshold quantity of a regulated substance to develop a risk management plan.

According to the EPA, a risk management plan must:

- identify the potential effects of a chemical accident;
- identify the steps the facility is taking to prevent an accident; and
- spell out emergency response procedures should an accident occur [11].

In addition, the EPA's RMP rule defines three Program levels (Program 1, 2, or 3) based on the potential consequences to the public and the effort needed to prevent accidents [12, p. 1]. Program 1 is the least stringent of these three Program levels and Program 3 is the most rigorous.

For Program 3 processes, the company must submit one risk management plan for all processes covered, including at least one worst-case and one alternative release analysis for all toxic substances over the threshold quantity. Additionally, the company must implement all the elements of the Program 3 prevention program (process safety information, process hazard analysis, standard operating procedures, training, mechanical integrity, compliance audits, incident investigations, management of change, pre-startup reviews, contractors, employee participation, and hot work permits), develop an emergency action or response plan and program, and coordinate with local responders [12, pp. 18-20].

[a] https://www.osha.gov/ords/imis/establishment.inspection_detail?id=1765826.015. At the time of publishing this report, the case remains open and the citations are contested.

[b] 40 C.F.R. § 68.130

Cuisine Solutions identified its ammonia refrigeration process at the Sterling plant at the Program 3 level because of its proximity to public receptors near the toxic endpoint[a] for a worst-case release and because the OSHA PSM standard already covered the process [12, p. 12]. The risk management plan completed on behalf of the company in July 2024 identified 17 public receptors within a 1.1-mile radius, including the Ashburn Post Office, several industrial parks, two historical sites, a cemetery, a golf club, and other receptors.

1.6 International Institute of All-Natural Refrigeration

As discussed in **Section 1.5** above, ammonia refrigeration systems that contain over 10,000 pounds of anhydrous ammonia must meet the requirements of the OSHA PSM standard and the EPA's RMP rule. However, smaller systems are common in the United States, and all ammonia refrigeration systems should follow Recognized and Generally Accepted Good Engineering Practice (RAGAGEP) [7, p. 3.1].

While the ASME Boiler and Pressure Vessel Code still applies to the refrigeration industry [13, p. 43], most refrigeration systems follow standards issued by the International Institute of All-Natural Refrigeration (IIAR)[b] as RAGAGEP [7, p. 3.1]. The IIAR has issued a series of standards and guidelines, some of which have been adopted by the American National Standards Institute (ANSI) [13, p. v]. One of these standards, ANSI/IIAR 2-2021, *Standard for Design of Safe Closed-Circuit Ammonia Refrigeration Systems* ("ANSI/IIAR 2"), provides guidance for the design of relief systems in ammonia refrigeration service [13, p. 51].

Several standards organizations such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the International Code Council (ICC) have deferred to the IIAR for ammonia refrigeration standards.The IIAR has noted on its website:

> As of the 2021 model codes, the International Mechanical Code (IMC), ASHRAE-15, the Uniform Mechanical Code (UMC), and the National Fire Protection Association (NFPA), all agreed to defer to IIAR-2 and other IIAR standards as the entire basis of regulating ammonia… [14]

The EPA and OSHA also refer to IIAR standards as RAGAGEP. The EPA references IIAR standards in guidance for RMP compliance [7, p. 3.1]. OSHA highlights IIAR standards and other documents related to ammonia refrigeration on a web page dedicated to ammonia refrigeration [15].

1.7 Description of Surrounding Area

Figure 9 shows the area surrounding the Sterling plant. The circles are set at one mile (blue), three miles (orange), and five miles (yellow) from the plant. Summarized demographic data for the approximate five-mile vicinity of the Sterling plant are shown below in **Table 1**. There are over 50,000 people residing in more than 18,000 housing units, most of which are single family units, within five miles of the plant. The area also

[a] The EPA defines the "toxic endpoint" as "the maximum airborne concentration below which it is believed that nearly all individuals can be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action." For ammonia, the toxic endpoint concentration is 200 ppm [24, p. 4].

[b] The Institute was formerly known as the International Institute of Ammonia Refrigeration, and some documents referenced in this report were published under that name.

includes Washington Dulles International Airport, the Loudoun Gateway Silver Line Metro station, and a United States Post Office. Detailed demographic data are included in **Appendix B**.

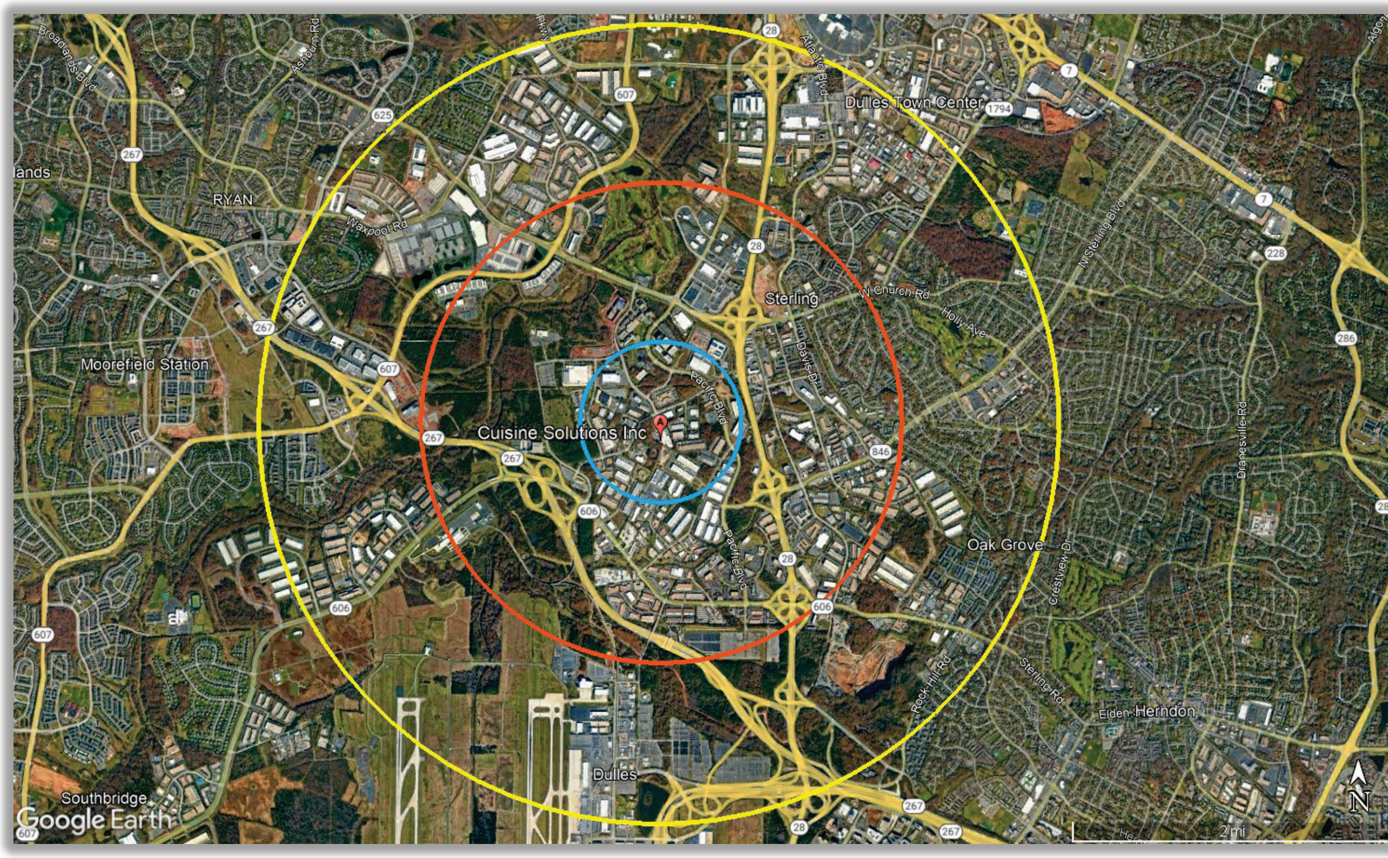

Figure 9: Area surrounding the Sterling plant. (Credit: Google Earth, annotated by CSB)

Table 1: Summarized demographic data (Credit: CSB using data obtained from Census Reporter[a])

Population	Race and Ethnicity (%)		Per Capita Income ($)	Poverty (%)	Number of Housing Units	Types of Housing Units (%)	
50,926	White	39	57,924	4.6	18,431	Single Unit	71
	Black	7				Multi-Unit	29
	Native	0				Mobile Home	0
	Asian	26				Boat, RV, Van, etc.	0
	Islander	0					
	Other	1					
	Two+	3					
	Hispanic	24					

[a]This information was compiled using 2020 Census data as presented by Census Reporter [50]. Census Reporter is an independent project to make data from the American Community Survey easier to use. It is unaffiliated with the U.S. Census Bureau [51].

2 Incident Description

2.1 Chilled Water Upset

On the afternoon of July 31, 2024, approximately between 5:00 p.m. and 5:30 p.m., the second shift refrigeration technician received a radio call indicating that all three of the water pumps in Tank Farm 5 supplying chilled water to the sous vide process were shut down. The technician believed the water pumps had shut down due to high temperature inside an outdoor electrical cabinet that was in direct afternoon sunlight.

At approximately 5:40 p.m., the refrigeration technician arrived at Tank Farm 5 and confirmed that none of the chilled water pumps were running. The refrigeration technician opened a door on the outdoor electrical cabinet and could feel the heat coming out of it. The technician tried to reset the chilled water pumps, but as soon as the motors were reset, the pumps shut off again. The refrigeration technician then left the electrical cabinet doors open to reduce the temperature inside. As the sun was setting, the refrigeration technician found that the temperature was becoming noticeably cooler near the electrical cabinet. At approximately 6:14 p.m., the refrigeration technician restarted the chilled water pumps, and this time the pumps continued to operate.

After approximately 8:00 p.m., the refrigeration technician received another radio call, stating there was an issue with the Tank Farm 5 chilled water temperature for the sous vide process. At approximately 8:17 p.m., the refrigeration technician returned to Tank Farm 5 and looked at all three heat exchangers in the refrigeration loop. The technician later told the CSB that, at that time, the ammonia pressures were in the normal operating range. Additionally, all the surge drum sight glasses indicated a stable, normal level of liquid ammonia, and the refrigeration equipment appeared to be working correctly. The refrigeration technician recalled stating on the radio at that time: "Hey, everything looks good on our end […] check how many batches you're cooking…". The refrigeration technician then left the Sterling site for a meal break at approximately 8:19 p.m.

2.2 Ammonia Release

At approximately 8:23 p.m., a quality assurance employee returned to the Sterling plant after taking a break. As the employee walked back to the main employee entrance, as shown in **Figure 10**, the employee walked into "what smelled and felt like a chemical cloud." The employee told CSB investigators that there was no visual cloud or anything that looked different outside that evening, but the employee felt their eyes "forcefully started tearing up" and their nose and throat become "constricted." The employee also stated that they were in an "immediate state of confusion" as they entered the plant.[a]

[a] The odor threshold for ammonia is 5 to 50 ppm in air, according to OSHA [4].

Figure 10: Sterling plant employee entrance and parking lot. (Credit: Cuisine Solutions, annotated by CSB)

The employee went to the office and told an assistant manager what they had just experienced outside and how strong the smell was. The assistant manager radioed maintenance employees for assistance in identifying the odor. One of the maintenance technicians recalled hearing someone say, “I need a maintenance man. People are saying they smell gas in the parking lot…” on the radio.

At approximately 8:27 p.m., maintenance employees reached the plant employee parking lot to investigate and observed a white cloud coming out of the common relief header tee diffuser on the ammonia refrigeration system (**Section 1.4.3**), as shown in **Figure 11**. One maintenance employee described witnessing ammonia leaving the open-ended vent piping “like a bubble cloud, like coming down, you know, dropping. And then it would shut off, and then it’d come back again, and then it’d shut.” Another maintenance employee told CSB investigators, “You could see the ammonia cloud. It was, I mean, like I say, it was a cloud. It was something I’ve never seen before. You know. You smell it and you know it’s bad. But from what I’ve been told, when you see it, it’s really bad.” Consistent with these reports, security camera footage showed a visible cloud forming and dissipating, and a second cloud forming as the release progressed.

Figure 11: Visible ammonia cloud during the release (left), and the release point (circled, right) through a horizontal tee diffuser. (Credit: Cuisine Solutions employees, annotated by CSB)

At approximately the same time, one of the responding maintenance employees called the offsite refrigeration technician to let the refrigeration technician know that there was an ammonia odor in the employee parking lot. The refrigeration manager also received a call describing the ammonia release, after which the refrigeration manager started driving to the Sterling plant from home.

Meanwhile, workers inside the building, in a cafeteria and break area adjacent to the ammonia release point, as shown in **Figure 12**, recalled identifying and reporting an ammonia odor at the time.

Figure 12: Overhead view of the Sterling site, indicating the break area (blue rectangle), emergency exits compromised, and some commonly used evacuation routes (green arrows). (Credit: Google Earth, annotated by CSB)

2.3 EVACUATION

At approximately 8:27 p.m., the production manager[a] directed employees by radio to evacuate the building via the opposite (east) side of the building, as shown in **Figure 12**. The production manager told the CSB that they were aware that the emergency exit doors on the west side of the building led directly into the white cloud.

Because only plant supervisors and technicians carried radios, many workers did not receive the evacuation radio message directly. Surveillance video showed that many workers throughout the production areas were instructed to evacuate in person and immediately did so. Other workers already outside and near the ammonia release beckoned through the windows to workers inside. Some workers exited the building near or into the white ammonia cloud and likely inhaled the toxic gas. Portions of the toxic ammonia vapor cloud were not

[a] As shown in **Section 1.2**, the production manager was the highest-ranking employee onsite during the second shift and was responsible for all operations on the shift.

visible, and the ammonia harmed some evacuees because they walked into the invisible portions of the ammonia cloud before they realized it was there.

Multiple workers later told CSB investigators that they smelled ammonia as they evacuated along the east side of the building and along the evacuation route directed by the production manager, as shown in **Figure 12**. Eyewitness accounts and security camera footage confirmed that there was no visible cloud on the east side of the building.

The local wind direction and wind speed at the time of the incident[a] were from the south-southeast at approximately 7.5 miles per hour, although the winds shifted slightly throughout the hour.[b] The "Initial Muster Point" in **Figure 13** was abandoned immediately due to ammonia odors. Many evacuees then moved to the location marked "Relocated Muster Point" in **Figure 13**, which was approximately 1/3 mile away from the initial muster point, to escape the ammonia odor.

[a] The nearest weather station to the site was at Dulles International Airport, approximately 2.7 miles south of the plant.

[b] Appendix D at page 42.

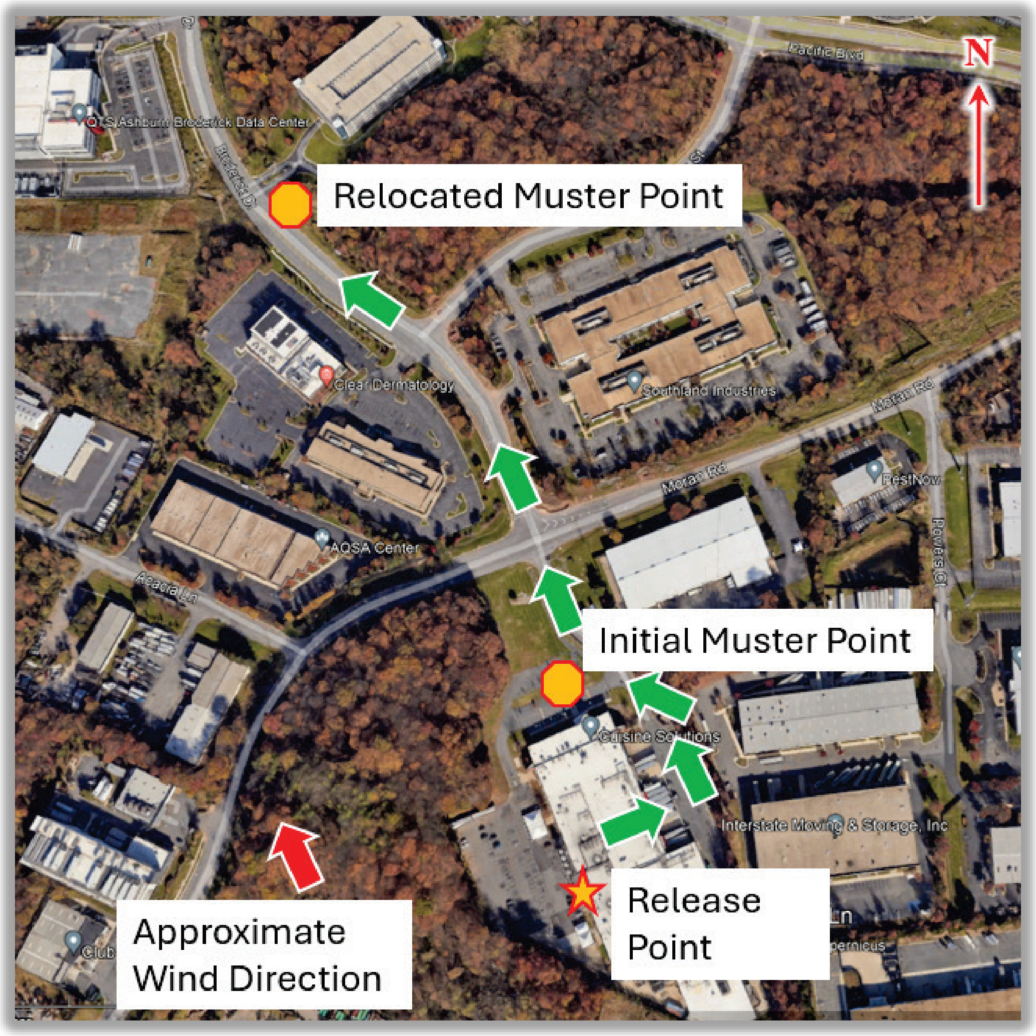

Figure 13: The evacuation route (green arrows) that most evacuees followed via the east side of the building to avoid the release on the west side (yellow star). (Credit: Google Earth, annotated by CSB)

The refrigeration technician returned to the employee parking from his off-site meal break lot at approximately 8:40 p.m., by which time the evacuation was virtually complete.

Throughout the incident, none of the alarms from the ammonia detection sensor system inside the production areas activated, and no site-wide evacuation alarm sounded.[a] However, the refrigeration technician later told CSB investigators that the ammonia sensor in the Tank Farm 5 emergency pressure relief discharge piping was reading 10,000 parts per million (ppm) on the Sterling plant's HMI screen sometime after 8:40 p.m.

[a] No atmospheric ammonia sensors existed outside the building, where the release occurred.

2.4 EMERGENCY RESPONSE

At approximately 8:31 p.m., the Loudoun County Emergency Communications Center received a 911 call from a Sterling plant employee reporting an ammonia odor "coming out from the pipes" [16]. Soon thereafter, the supervisor at the Postal Inspection Service across the road from the Sterling site called 911. The supervisor told the 911 operator, "you can barely breathe outside" and asked for advice on the developing situation. The Loudoun County Fire and Rescue, including the Hazardous Materials Response Team (the "HAZMAT team"), arrived on the scene,[a] confirmed that the leak was ammonia, and observed and treated numerous individuals who appeared to have been exposed [16]. The first responders reported "no visible hazards from the exterior" of the building upon arrival. Fire and Rescue units from Fairfax County, Prince William County, and the Metropolitan Washington Airports Authority also responded and assisted at the scene, which included "more than ten unconscious individuals identified," according to Loudoun County Incident Command.

The refrigeration technician encountered emergency responders who were entering the building at approximately 8:46 p.m. The refrigeration technician and one of the emergency responders returned to the ammonia compressor room, and at the emergency response team's suggestion, the refrigeration technician shut down each compressor using the compressors' local control panels, thereby shutting down the refrigeration system.

The refrigeration manager arrived at the plant and closed the king valve (**Figure 3** above) at approximately 8:55 p.m. The refrigeration manager had been advised that the compressors had been shut down already through a phone call with the refrigeration technician. After closing the king valve, the refrigeration manager met with emergency responders and prepared to enter the Tank Farm 5 area to attempt to isolate the source of the ammonia release.

At approximately 9:29 p.m., with the HAZMAT team's guidance and support, the refrigeration manager switched the Heat Exchanger 5 Surge Drum three-way selector valve to isolate the emergency pressure relief valve that had released the ammonia and put the standby emergency pressure relief valve in service (**Figure 14**). The manager later told the CSB that he determined which emergency pressure relief valve was releasing ammonia into the atmosphere based on his observation of frost buildup on the exterior of the piping and emergency pressure relief valve.

[a] The initial 911 call was placed at 8:31 p.m. Loudoun County Fire and Rescue was dispatched at 8:36 p.m. The first response vehicle arrived on the scene at approximately 8:42 p.m.

Figure 14: Image from video of the incident scene. Emergency responders working with a Sterling plant employee to safely isolate the ammonia. (Credit: WTVR-TV [17])

Due to their exposure to the ammonia vapor, some personnel experienced headaches, nausea, vomiting, and irritation to the nose and throat, causing coughing and wheezing, consistent with ammonia inhalation, during the evacuation. As discussed in **Section 2.3** above, evacuees moved to the location marked "Relocated Muster Point" in **Figure 13** to escape the ammonia odor. **Figure 15** shows an aerial image of the relocated muster point during the incident response.

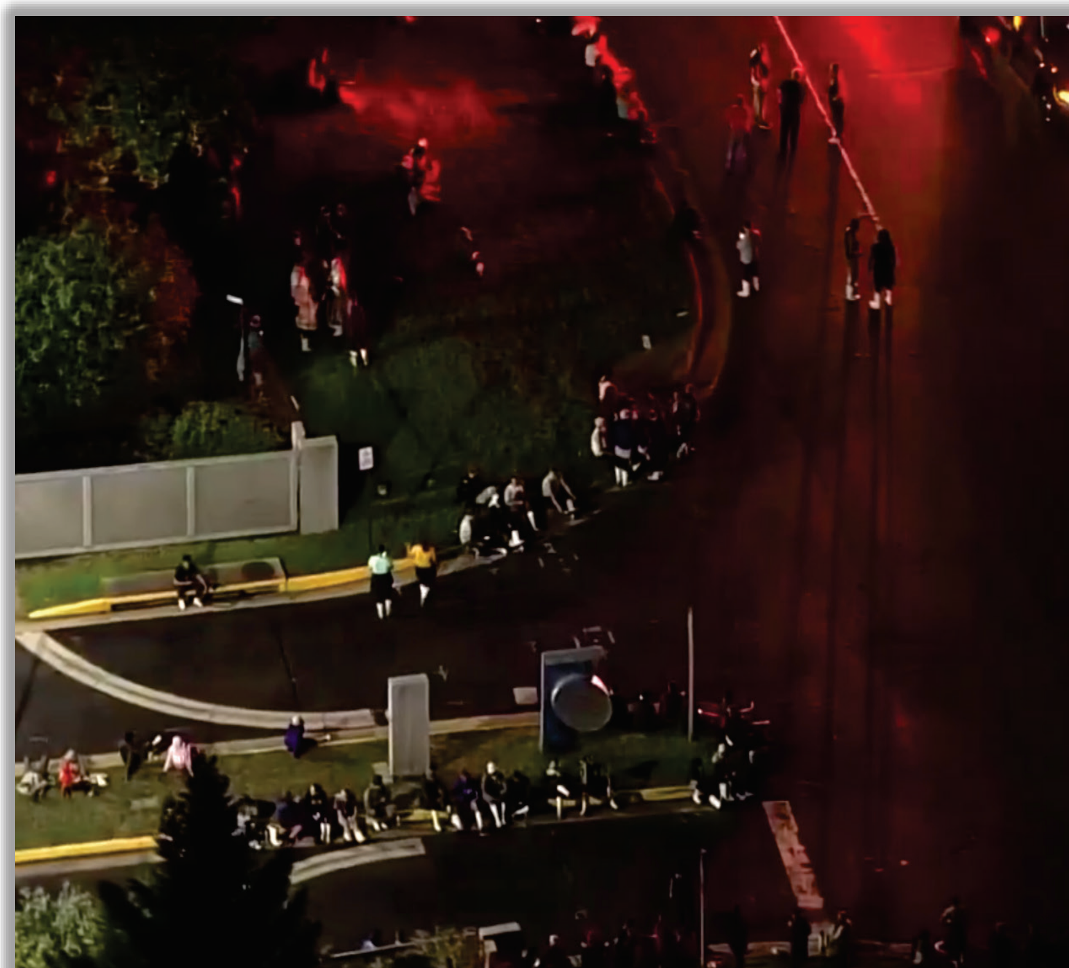

Figure 15: Image from video of the incident scene showing evacuees and emergency responders gathered at the relocated muster point north of the Sterling site. (Credit: WTVR-TV [17])

Due to the number of potential patients and the type of medical conditions presenting, the incident commander requested a Mass Casualty Incident alarm, which resulted in an additional 10 emergency medical services transport units, 10 suppression units, a mobile ambulance bus, command staff support, and other resources responding to the scene [16].

The Loudoun County Fire and Rescue team ventilated the building to remove residual ammonia and then returned control of the scene to Cuisine Solutions at approximately 11:46 p.m. Meanwhile, Cuisine Solutions officials accounted for all 286 personnel onsite during the incident.

A summary of key events is shown in **Figure 16**.

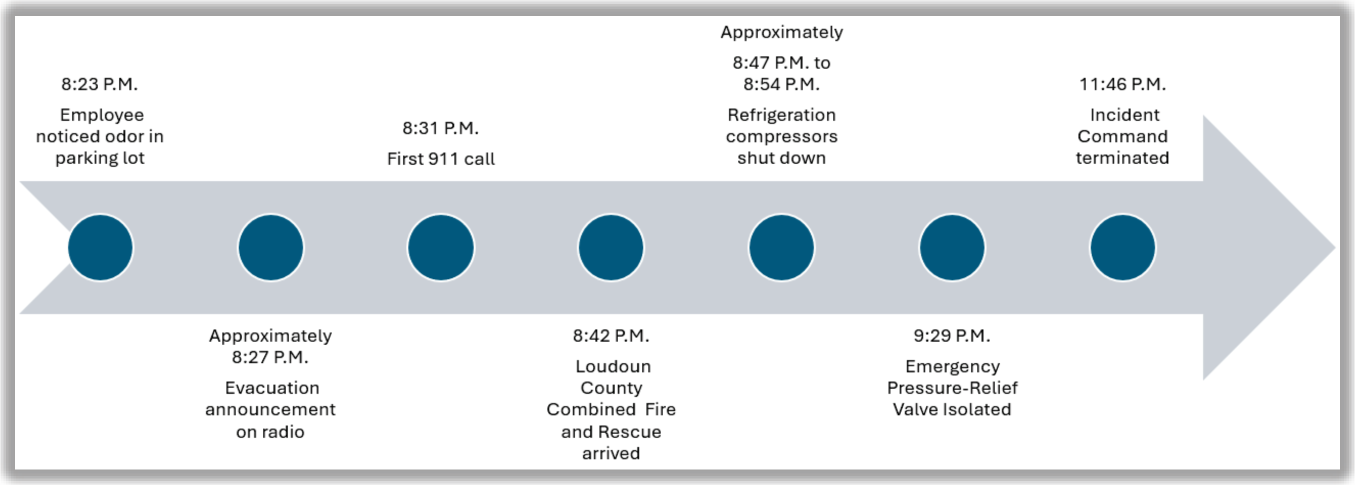

Figure 16: Timeline of key events. (Credit: CSB)

2.5 Incident Consequences

Emergency responders assessed 267 workers and transported 33 workers to area hospitals on the night of the incident. Four of those workers were admitted to area hospitals and one of those was placed in an intensive care unit. Cuisine Solutions reported that another seven people self-presented at local hospitals and urgent care facilities after the incident, and that all patients were released within a week. Additionally, Cuisine Solutions estimated business and property losses to be approximately $3 million. One of the food production lines was shut down for approximately 16 days, and another production line was shut down for approximately 38 days.

3 TECHNICAL ANALYSIS

3.1 EMERGENCY PRESSURE RELIEF VALVE OPENED

During the incident, ammonia exited the refrigeration process through the common relief header in Tank Farm 5, which was the discharge path for 18 emergency pressure relief valves (**Section 1.4.3**). The refrigeration manager told the CSB that he determined which emergency pressure relief valve opened based on the presence of frost on the discharge piping exterior. Saturated liquid or vapor ammonia at atmospheric pressure is -28 °F, and atmospheric moisture will freeze in contact with the cold pipe [13, p. 13, 18, p. A.4]. The refrigeration manager traced the source of the release to the Heat Exchanger 5 Surge Drum emergency pressure relief valve using the frost as a guide. The refrigeration manager then switched the three-way selector valve to take the emergency pressure relief valve that had opened offline, and put the standby emergency pressure relief valve online. By the time the switch occurred at approximately 9:29 p.m., however, the overpressure event was over and neither emergency pressure relief valve opened.

Of the 18 emergency pressure relief valves connected to the Tank Farm 5 common relief header at the time of the incident, 15 were the same size and model and had the same set pressure of 300 psig, including the ones installed on the Heat Exchanger 5 Surge Drum.[a] Additionally, tags on the emergency pressure relief valves indicated that the valves had likely been in service for approximately seven years and were two years overdue for replacement or testing.[b] Standard ANSI/IIAR 6 (2019), *Standard for Inspection, Testing, and Maintenance of Closed-Circuit Ammonia Refrigeration Systems* ("ANSI/IIAR 6"), requires that emergency pressure relief valves be tested or replaced every five years [19, p. 43]. For these reasons, the CSB had all 15 emergency pressure relief valves tested at an independent shop facility certified to test such devices.[c]

The results of the CSB's testing are summarized in **Figure 17** below and detailed in **Appendix C**. Each emergency pressure relief valve was tested three times to determine the pressure at which it opened. According to the Industrial Refrigeration Consortium (IRC), acceptable performance is that an emergency pressure relief valve will remain closed and hold pressure up to 90 percent of the set pressure [20, p. 15]. All 15 emergency pressure relief valves functioned as designed, and none opened prematurely.

The pressure at which each of the valves reclosed after opening, also known as "blowdown," was also recorded in each test. The blowdown results indicated that all emergency pressure relief valves tested reclosed within the expected blowdown pressure range specified by the manufacturer [21, p. 61]. A failed or faulty emergency pressure relief valve could remain open well below the blowdown pressure, increasing the quantity of ammonia released, but that did not appear to be the case in this incident.

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[a] All 15 emergency pressure relief valves were a Cyrus Shank Model 800 QR, made of 316 stainless steel, with a ½-inch inlet and ¾-inch discharge nominal size.

[b] Although some of the emergency pressure relief valves were still tagged indicating they had been installed as part of the Tank Farm 5 project installation in 2017, some tags were missing. Consequently, the CSB could not verify the service life of all 15 emergency pressure relief valves. Cuisine Solutions personnel believed that all Tank Farm 5 emergency pressure relief valves were installed in 2017 and remained in service until August 1, 2024, but no records could be found to verify this. After the incident, the company replaced all Tank Farm 5 emergency pressure relief valves.

[c] The National Board of Boiler and Pressure Vessel Inspectors offers a "VR Stamp for the repair of pressure relief valves" [48]. The shop used to test the Sterling plant emergency pressure relief valves held a VR stamp.

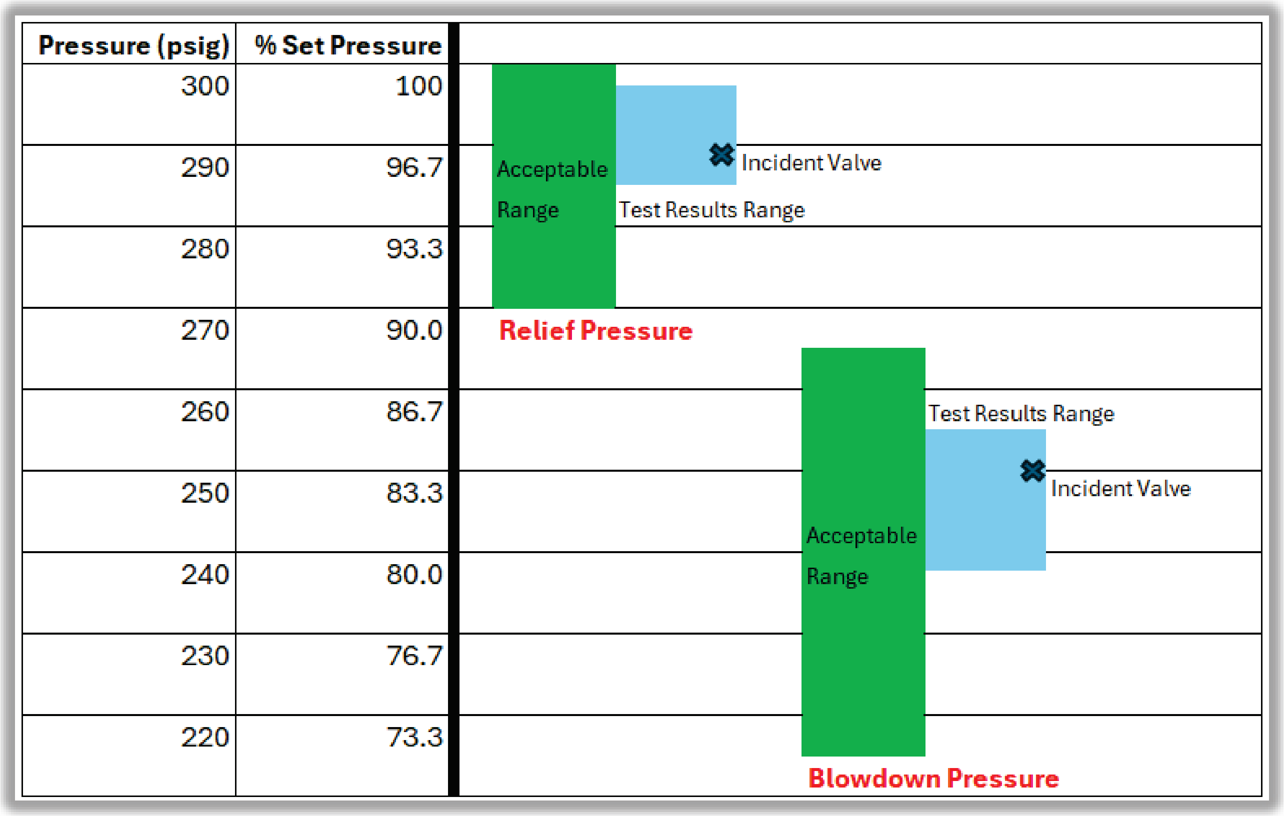


Figure 17: Emergency pressure relief valve testing results, with an average of three tests for each device. The blue crosses represent the device believed to have opened during the incident. (Credit: CSB)

The CSB concludes that although the Tank Farm 5 emergency pressure relief valves were likely beyond the 5-year replacement or testing frequency, failure to test or replace them on time was not causal to the incident.

Based on the test results above in **Figure 17**, premature failure of the emergency pressure relief valves could be ruled out. This means that an overpressure in the Heat Exchanger 5 Surge Drum occurred, which caused the emergency pressure relief valve to open.

The CSB concludes that the ammonia release resulted from an emergency pressure relief valve opening on the Heat Exchanger 5 Surge Drum due to an overpressure event, and that the emergency pressure relief valve functioned as designed and intended in this event.

3.2 Potential Overpressure Scenarios

Cuisine Solutions did not record historical process data for the ammonia refrigeration system beyond food storage, chiller, or freezer temperatures required for food safety concerns. Through interviews after the incident, the CSB learned that a few hours before the incident, the water pumps shut down in Tank Farm 5, apparently due to the electrical cabinet for the pumps becoming overheated, as described above in **Section 2.1**. Only water tank level and temperature data were available for Tank Farm 5. The data indicated some water tank temperature fluctuations and high water temperatures on the afternoon before the incident, but this began hours before the incident occurred, and the CSB could not verify whether the water tank bulk temperature data were related to the Heat Exchanger 5 Surge Drum overpressure in the absence of any other process data. The Sterling plant's HMI[a] included an alarm summary page, but any record of the alarms that occurred during the incident was lost, according to Cuisine Solutions. This lack of process historical data and alarm history for the refrigeration process hampered the CSB's investigation into the cause of the emergency pressure relief valve opening. Consequently, the CSB could not determine the specific cause of the overpressure or upset condition.

KEY LESSON

Companies should ensure that they measure and store process data so that when an incident or process upset occurs, they can analyze the data, determine the causes, and make changes to stop the upset or prevent another incident. The inability to access such process data can mask serious process control problems. Employees cannot respond to a process upset or prevent future ones if they cannot see how a process upset developed. Investigating an incident without sufficient process data hampers investigation and makes a repeat incident more likely to occur.

The CSB considered possible scenarios that could create an overpressure in the Heat Exchanger 5 Surge Drum, however. Some scenarios could be ruled out and conclusions made based on events that clearly did *not* occur, even in the absence of process data:

- Since there was no evidence that any fire occurred, scenarios involving fire, such as a pool fire[b] under the Heat Exchanger 5 Surge Drum, could be ruled out.
- Since there was no evidence of an overpressure in any other vessels in the refrigeration system, such as any other emergency pressure relief valves activating and no other ammonia releases, the overpressure had to be localized to Heat Exchanger 5 and/or its Surge Drum.
- Because the ammonia vessels upstream (HPR) and downstream (HTA) of the Heat Exchanger 5 Surge Drum did not overpressure or activate the emergency pressure relief valves, high pressure could not have originated from upstream or downstream vessels sufficient to overpressure the Heat Exchanger 5 Surge Drum. In fact, the HPR and HTA both had emergency pressure relief valves set at lower pressure (250 psig) than the emergency pressure relief valve set pressure on the Heat Exchanger 5 Surge Drum (300 psig).
- After the incident, a test protocol was performed on the heat exchangers in Tank Farm 5. None of the heat exchangers exhibited any leaks. The chilled water therefore did not leak into the ammonia side of the heat exchangers, and the ammonia did not leak into the chilled water.

[a] Human Machine Interface, described in **Section 1.1**.
[b] A pool fire is a "burning pool of liquid" [34, p. 7].

- A hydrostatic overpressure, also known as a liquid thermal expansion overpressure, where the surge drum would be isolated and full of liquid, likely did not occur because liquid could escape the surge drum through the vapor vent line and could not generate an overpressure simply by being liquid full. If the vent piping were blocked closed, a hydrostatic overpressure could occur, but it would not be sustainable such that it would cause a release lasting more than a few seconds. As soon as a very small volume of liquid was relieved, the pressure would dissipate, and the release would have stopped after only a few ounces of liquid were discharged. The release was observed to last approximately 10 minutes, which is not indicative of a simple hydrostatic overpressure.

The CSB found that for any overpressure event to occur in this incident, the pressure control valve or the surge drum vapor outlet piping had to be closed or restricted (**Figure 18** below). This scenario could include the pressure control valve orifice sizing simply being too small to vent the pressure generated in the surge drum fast enough to prevent overpressure.

Even with the vent closed or restricted, the saturated liquid ammonia in the surge drum had to reach 126 °F to achieve 300 psig, based on vapor-liquid equilibrium properties of ammonia [18, p. A.7]. Otherwise, even if the heat exchanger had not operated adequately, no overpressure could occur.

It is possible that abnormally hot water entered the heat exchanger from the sous vide line, and, with the surge drum vent closed or restricted,[a] the hot water could have provided the energy necessary for the ammonia side of the heat exchanger to reach 126 °F or higher, causing a boiling liquid or two-phase overpressure. **Figure 18** below illustrates this potential overpressure scenario.

However, other potential process upsets could also have caused the overpressure, coupled with insufficient venting through the vent line to prevent overpressure. Without process data, the CSB could not rule out multiple potential process upset scenarios.

[a] In this context, the control valve being undersized for this specific process upset also could have "restricted" the surge drum vent.

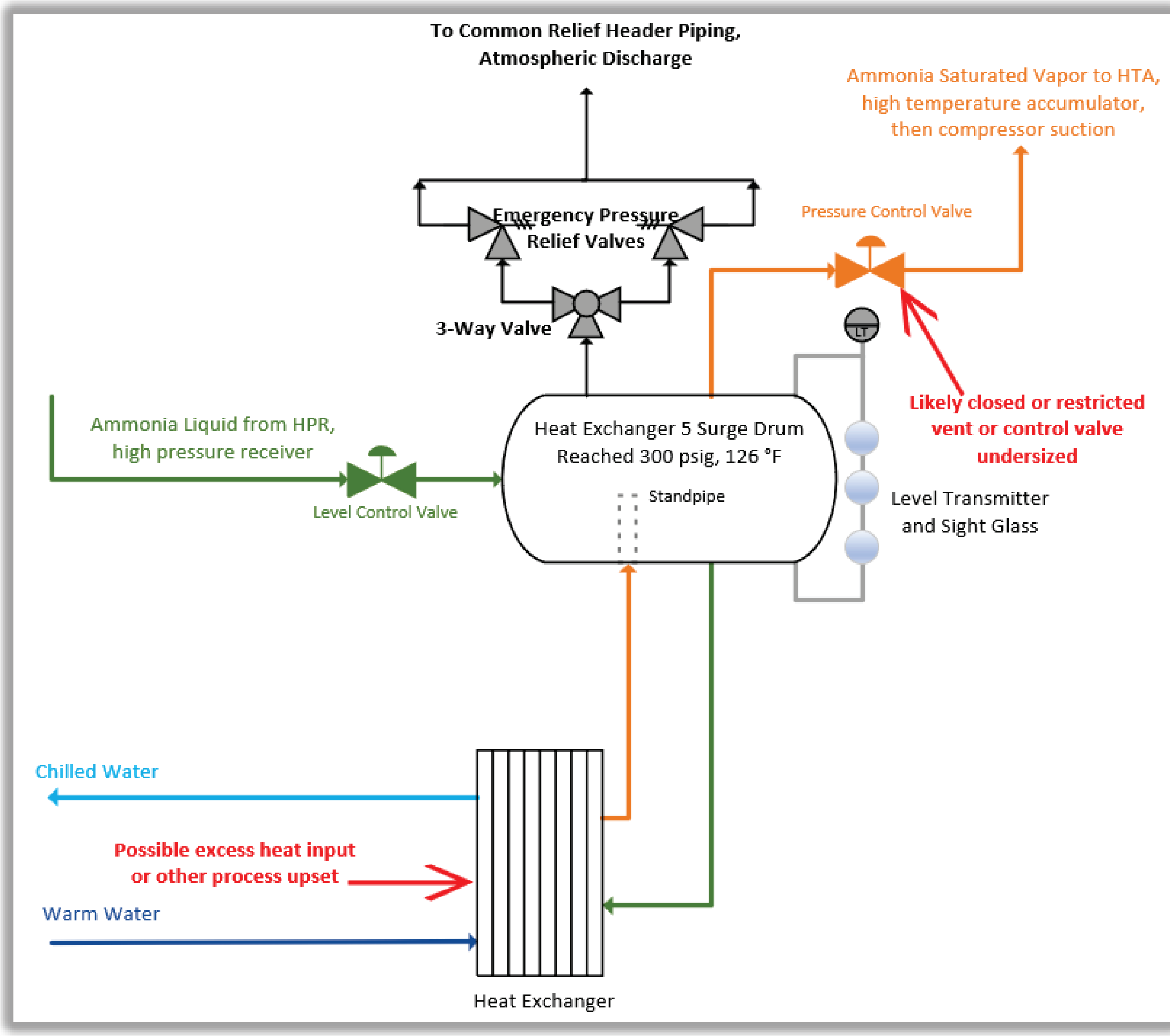


Figure 18: Heat Exchanger 5 Surge Drum potential overpressure scenario; closed or restricted vent combined with abnormal heat input. (Credit: CSB)

The CSB concludes that the ammonia release resulted from an overpressure event, and that a closed or restricted outlet on the Heat Exchanger 5 Surge Drum, combined with a process upset, likely initiated the event. Without process data available for analysis, however, the specific cause of the process upset could not be determined.

3.3 Ammonia Cloud

The CSB contracted an independent third party to conduct a dispersion analysis of the ammonia release. A dispersion analysis is "an evaluation of the predicted outcome from an incident and how it affects the surrounding equipment and people" [22]. The analysis includes mapping the potential vapor cloud resulting from a toxic release.

The purpose of the dispersion analysis was to determine the conditions that could cause the observed ground-level ammonia cloud and to estimate evacuee exposure concentrations. The analysis used the Process Hazards Analysis Software Tool (PHAST) model version 9.0 to visually represent the ammonia cloud contours and explain the cloud's behavior. The detailed report for the modeling study is in Appendix D. The release flow rate for each case was based on the conditions modeled for each case (Table 2 in Appendix D). The modeling considered several factors expected to affect ammonia concentrations at ground level, including:

- weather conditions at the time of the incident;
- the amount of liquid aerosolized[a] in the release;
- the discharge velocity;
- the discharge piping configuration; and
- the ammonia release elevation.

In modeling cases involving a tee diffuser at the piping termination, the PHAST model cannot model both discharges of the tee. Consequently, only the south-facing half of the tee was modeled and plotted for these cases. The south side of the tee faced the employee entrance and one of the evacuation routes. In reality, there would also be a mirror-image discharge 180 degrees away from the modeled discharge, making a two-lobed, though not necessarily symmetrical, cloud. The plots below illustrate the dispersion model for only one side of the tee discharges. These plots are referred to as "half cloud" curves throughout this report.[b]

3.3.1 Ammonia Concentrations

Dispersion analyses can use various established concentration guidelines to determine the effects on humans in a release.

Some of these are called Emergency Response Planning Guidelines (ERPGs) and fall into three categories:

- ERPG-1 is "the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects." For ammonia, the ERPG-1 value is 25 ppm [23, pp. 780-781].

- ERPG-2 is "the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action." For ammonia, the ERPG-2 value is 150 ppm [23, pp. 780-781].

[a] An accidental release can include aerosol clouds, usually consisting of liquid droplets, vapor, and air. Aerosol droplets can be small, 5 microns or less [27, p. 36].

[b] See Appendix D, at page 6.

- ERPG-3 is "the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects." For ammonia, the ERPG-3 value is 1,500 ppm [23, p. 781].

Another commonly used guideline is the Immediately Dangerous to Life or Health (IDLH) concentration established by the National Institute for Occupational Safety and Health (NIOSH)[a] for many chemicals to characterize high-risk exposure scenarios. According to NIOSH, "IDLH values are established to ensure that the worker can escape from a given contaminated environment in the event of failure of the respiratory protection equipment and to indicate a maximum level above which only a highly reliable breathing apparatus, providing maximum worker protection, is permitted" [23, p. 783]. IDLH concentrations are used to protect workers and the public from short-term and rare-event chemical exposures [23, p. 784] . The IDLH concentration for ammonia is 300 ppm [6, pp. 4-5].

For EPA RMP reporting of consequence analyses, the EPA defines the "toxic endpoint" identically to the ERPG-2 concentration defined above [24, p. 4]. Even though the definitions are the same, however, the concentration values are different. The EPA uses 200 ppm as the toxic endpoint for ammonia [24, p. 4], as opposed to the 150 ppm ERPG-2.

3.3.2 WEATHER CONDITIONS

The CSB's dispersion modeling used actual weather station conditions at Washington Dulles International Airport as near as possible to the time of the release. The airport is approximately 2.7 miles from the Sterling site, giving the dispersion model realistic weather data on which to base the model. At the nearest times before and after the incident, the wind was out of the south-southeast at an average of 7.5 miles per hour, the average temperature was 85 °F, and the average relative humidity was 60 percent.

All cases run in the dispersion modeling used the same weather conditions. Modeling results, therefore, cannot be extrapolated to other conditions but were intended to estimate the actual cloud that occurred during the incident on July 31, 2024.

3.3.3 VISIBLE CLOUD

As described in **Section 1.3**, anhydrous ammonia condenses atmospheric moisture when cold ammonia contacts warm humidity in the air [25, p. 29]. During the incident, the condensing moisture made the ammonia cloud briefly visible (a few seconds to a few minutes) after it exited the relief discharge piping. Because the atmospheric humidity was high at the time, the ammonia cloud was visible in videos of the release. The visibility of the cloud was a key clue to the properties of the ammonia cloud and the process conditions that may have created it.

[a] NIOSH "is the federal institute responsible for conducting research and making recommendations for the prevention of work-related injury and illness" [49]. https://www.cdc.gov/niosh/about/index.html

3.3.4 LIQUID AEROSOL IN THE RELEASE

At the 36th Annual IIAR meeting in 2014, a modeling study of outdoor ammonia emergency pressure relief discharges was presented, titled *Modeling of Releases from Ammonia Refrigeration Pressure Relief Valves Using Dispersion Modeling Software* ("Technical Paper #6").[a] This study examined the impact of factors such as liquid droplets entrained in the release, called "aerosols," release orientation (vertically upward, horizontal, or downward), discharge velocity, and discharge elevation [26, p. 1]. This modeling study used an older version of PHAST, but it was similar to the dispersion analysis performed for this incident. Throughout this report, findings from Technical Paper #6 are used for reference and comparison to the CSB's dispersion analysis and industry standards and good practices.

The first observations from videos of the Sterling plant's ammonia release were that much of the visible cloud slumped to the ground near the point of release and that at least part of the cloud did so within just a few seconds. The presence of liquid ammonia in the discharge increases the cloud density because of both the high liquid density and the cold temperatures generated by flashing droplets. Even a small amount of liquid or aerosol in a release can create greater exposure risks because a colder, more dense cloud can slump to ground level, potentially coming into contact with people. **Table 2** below illustrates this point. In modeling several release scenarios for ammonia refrigerant, Technical Paper #6 noted a significant difference in properties between a warm vapor release, a cold vapor release, and an aerosol release as ammonia exits the relief discharge. For example, warm ammonia vapor has a specific gravity relative to air of 0.58, meaning it would be buoyant in air. An ammonia release with 12 weight percent liquid aerosol has a specific gravity of 6.04 (highlighted in **Table 2** below), meaning it would slump to the ground before the ammonia could mix sufficiently with the surrounding air [26, pp. 18-19]. With time, the ammonia can warm to atmospheric temperature as it mixes with the surrounding air and absorbs enough heat to evaporate, becoming warm, buoyant vapor. In the Sterling plant incident, there was evidence of significant liquid entrainment or two-phase flow, given the observable sink rate of the initial ammonia cloud, as shown in **Figure 19** below and the dispersion analysis results.

Table 2: Ammonia vapor and aerosol properties from *Modeling of Releases from Ammonia Refrigeration Pressure Relief Valves Using Dispersion Modeling Software* [26, p. 19]. (Credit: Timm)

Fluid	Condition	Temperature (°F)	Specific Gravity (relative to air at 77 °F)
Ammonia before mixing with air	Warm vapor	77	0.58
	Cold vapor	-28	0.74
	Ammonia vapor with liquid droplets, 12% mass fraction	-28	6.04
Ammonia in air	Ammonia aerosol in air, 0.0001% mass liquid remaining, 118,000 ppm ammonia	-90	1.38

[a] Throughout the rest of this report, this study will be referred to as "Technical Paper #6."

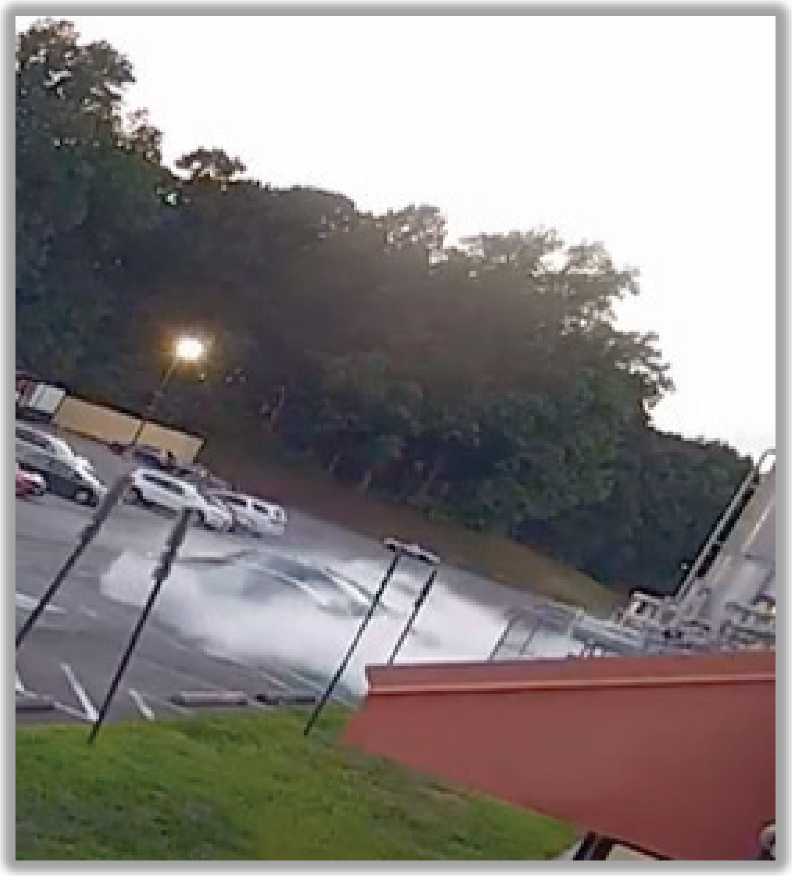


Figure 19: Part of the ammonia release rapidly slumped to ground level within 20-30 horizontal feet of the release point. (Credit: Cuisine Solutions)

The dispersion model in Appendix D compared various relief stream compositions, from 100 weight percent liquid at the emergency pressure relief valve inlet to 100 weight percent vapor at the inlet, as well as a few cases in between. None of the vapor-only cases exhibited the cloud behavior observed during the Sterling plant incident. **Figure 20** below shows the model half-cloud representing the release on the night of the incident if the release had been 100 weight percent vapor. In this model, the concentration at ground level is below 25 ppm (blue curve) and the cloud's IDLH concentrations (300 ppm, red curve) would remain at least 30 feet above ground. For this scenario, the model predicted no cloud slumping to ground level. Since cloud slumping to ground level could easily be seen in videos of the incident, a vapor-only release can be ruled out, as it does not accurately account for the dynamics of the actual release.

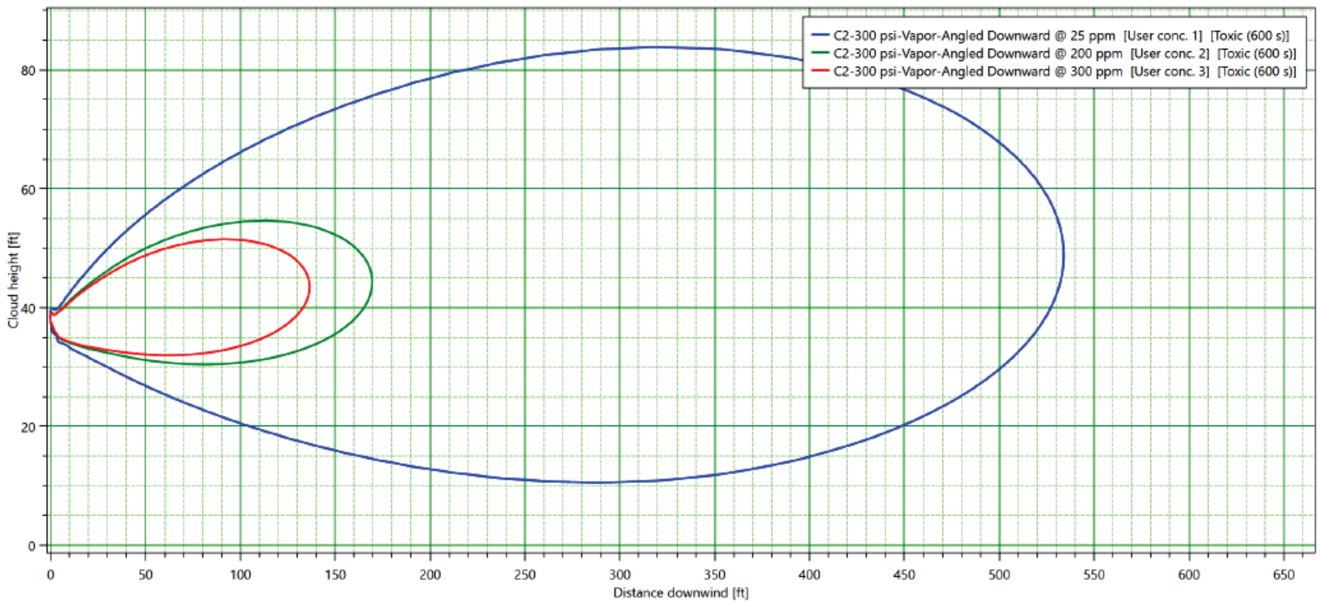


Figure 20: Half-cloud modeling of a vapor-only release on the night of the incident. Since this cloud remains aloft, a vapor-only release is not likely to have occurred. (Credit: CSB)

The CSB concludes that the ammonia release was not fully vaporized at the discharge to atmosphere because dispersion modeling of a vapor-only release does not fit observations of the ammonia cloud during the incident.

The dispersion analysis concluded that the actual release likely contained a significant liquid aerosol component. Based on observations from videos of the visible cloud and the results of the dispersion analysis scenarios, the dispersion analysis case that most closely resembled actual cloud behavior was 100 weight percent liquid at the emergency pressure relief valve inlet and 69 weight percent liquid at the relief piping discharge (case 1 in Appendix D).[a] This difference in liquid fraction in the model represents ammonia flashing across the emergency pressure relief valve orifice, through the relief discharge piping, and through the initial expansion to atmospheric pressure at the discharge point. The vapor-only case shown in **Figure 20** above indicated that IDLH ammonia concentrations remained roughly 30 feet above ground, while the liquid case in **Figure 21** below indicated that there were IDLH concentrations at ground level as far as 50 to 160 feet downwind (approximately). The dispersion analysis in Appendix D also indicated that the area exposed to IDLH concentrations at ground level increased with a higher liquid content in the discharge.[b]

KEY LESSON

While a dispersion analysis does not relate the visible cloud to the toxic cloud, the analysis, when paired with a video of the visible cloud, clearly shows that much of a toxic ammonia cloud can also be invisible. DO NOT approach an ammonia cloud without proper personal protective equipment (PPE).

---

[a] The purpose of dispersion modeling was not to quantify the liquid fraction in the release. The case cited was simply used to demonstrate that liquid was likely predominant in the release qualitatively. The model should not be overinterpreted in this scenario.

[b] See, for example, Figure 19 in Appendix D.

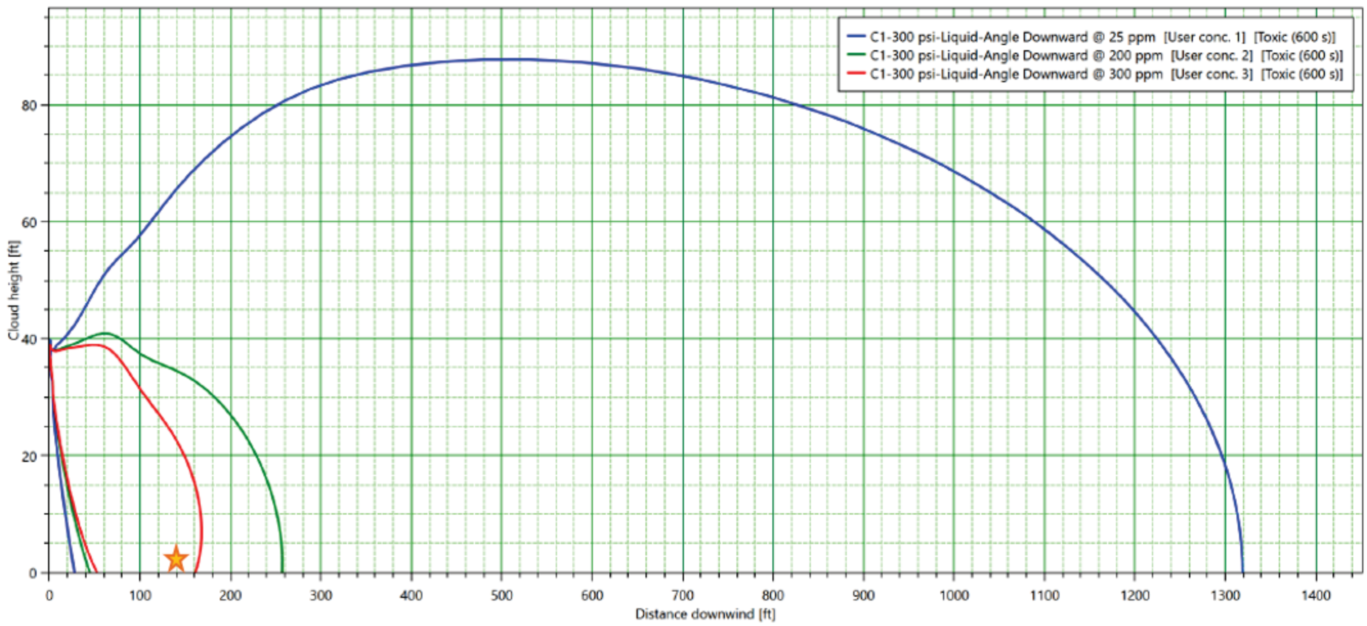


Figure 21: Half-cloud of the modeled case that most closely resembled actual cloud observations. The red curve is the IDLH 300 ppm boundary, green is 200 ppm, and blue is 25 ppm. The orange star indicates approximate location of the main employee entrance. (Credit: CSB)

The employee entrance was approximately 128 horizontal feet from the release point. **Figure 21** above shows that this entrance door (orange star) could have been in the IDLH cloud, meaning that dozens of evacuees who exited the building on the west side could have been exposed to ammonia vapors exceeding the IDLH concentration as they evacuated. At least two emergency exit doors were closer to the release than the employee entrance, but they were used by only approximately six people during the evacuation.

The CSB concludes that the ammonia release contained liquid aerosol, which resulted in a rapidly slumping ammonia cloud that reached ground level. The ground-level cloud likely contained IDLH concentrations of ammonia in areas that workers walked through while evacuating, including outside some of the plant's emergency exit doors.

3.3.5 Release Quantity

During the incident, the ammonia release likely stopped after the refrigeration technician stopped the compressors and the refrigeration manager closed the king valve (**Section 2.4**). Based on security camera footage and employee interviews, the CSB estimates that the release lasted at least 10 minutes.

Based on an estimated 10-minute release, the CSB estimates that the total release quantity was approximately 275 pounds of ammonia, using a release rate of 1,647 pounds per hour. This is the release rate for the liquid case that most closely matched the actual incident observations in the dispersion modeling (case 1 in Appendix D).[a]

[a] Cuisine Solutions estimated the release quantity at 170 pounds of anhydrous ammonia. This correlates to the emergency pressure relief valve vapor relief capacity, multiplied by a release duration of 20 minutes. The CSB release estimate is higher in part due to the liquid content in the release.

The CSB concludes that the release quantity was approximately 275 pounds, based on the predicted relief rate for a liquid relief scenario, which most closely represented the actual event.

This determination indicates the significantly larger impact that a release containing liquid aerosol can have compared to an all-vapor release. For a Program 3 process like the Sterling plant, the EPA's RMP rule requires a worst-case release analysis and at least one other alternative case analysis [12, p. 2.18]. Cuisine Solutions' alternative case was an all-vapor 900-pound ammonia release from the compressor room area, which indicated no predicted offsite effects, but did predict toxic endpoints in the employee parking lot and along evacuation routes. Even with significantly less ammonia, an aerosol release can have similar or worse consequences.

3.3.6 Building Wake Effects

During a release event, a plume that might otherwise rise or remain aloft can be pulled into a low-pressure wake region on or near the downwind, or leeward, side of an obstruction such as a building and be drawn down to the ground [27, p. 35]. Such phenomena are known as building wake effects. Therefore, ground-level personnel can be exposed to a toxic cloud even if the source is elevated and on the opposite side of a building. **Figure 22** below shows a generalized view of how the wake region can form downwind of a release on the leeward side of a building.

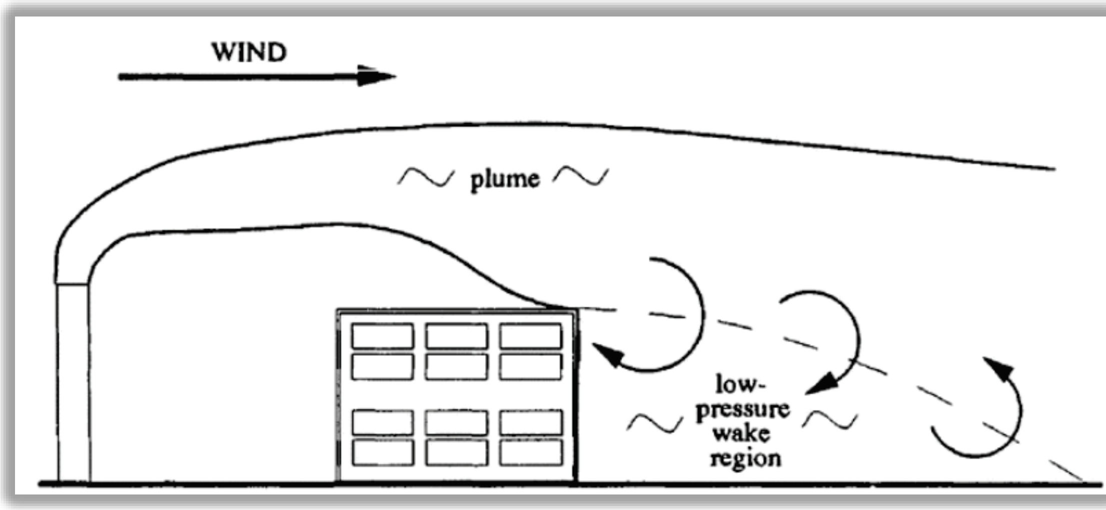


Figure 22: Generalized illustration of building wake on the leeward side of a building, drawing the plume down to ground level [27, p. 35]. (Credit: CCPS)

On the night of the incident, while a significant part of the ammonia cloud slumped to the ground initially, a portion of the visible cloud remained aloft and moved across the building's roof, even though a cloud was not visible on the east side of the building as described in **Section 2.3**. Nonetheless, video of the cloud indicated that some visible ammonia vapor moved across the roof of the building toward the north or east sides of the building, as shown in **Figure 23** below. In addition, the strong ammonia odors reported inside the building were due to ammonia migrating inside the building, likely through a Heating, Ventilation, and Air Conditioning (HVAC) unit intake on the roof near the relief discharge location (red box in **Figure 23**) from this buoyant portion of the ammonia release.

Figure 23: Much of the ammonia release slumped to the ground (lower left), but some remained aloft over the building roof (red oval). Note the HVAC unit in the visible cloud (red box). (Credit: Cuisine Solutions employees, annotated by CSB)

The CSB asked several evacuees where they had smelled ammonia during the evacuation. All of the evacuees interviewed by the CSB smelled ammonia near the northeast corner of the building, and some of them said that the odor was strongest there.[a] Security camera footage showed some evacuees hesitating as they evacuated and some temporarily turning back in this area during the evacuation, likely due to the odor. There was no visible cloud on the east side of the building, but at least one evacuee began to have difficulty walking and breathing in this area. **Figure 24** illustrates the evacuees' observations of the odor, compared with the evacuation route.

The supervisor at the Postal Inspection Service building across the road from the Sterling site called 911 during the incident and reported a strong odor outside the building (**Section 2.4**). The supervisor stated to the 911 operator "you can barely breathe outside," which indicates that at least some odor reached across the road, off the Cuisine Solutions Sterling site.

[a] These employees may not have been near the release on the west side of the building at any time, however.

Figure 24: Evacuees' odor observations (ovals) on the east side of the building, where evacuees walked (green arrows). (Credit: Google Earth, annotated by CSB)

The CSB concludes that although the release was on the west side of the building, building wake effects likely contributed to ammonia odors at ground level along the evacuation route on the east side of the building.

3.4 Potential Scenarios for Liquid in Relief Discharge

Many ammonia refrigeration emergency pressure relief systems are designed to relieve only vapor, and no liquid, from the vapor space of vessels [26, p. 14]. However, it is possible that liquid droplets or aerosols can discharge along with vapor in some relief scenarios. These scenarios can include (i) a vessel becoming overfilled with liquid, (ii) liquid swell leading to liquid carryover from a sudden pressure reduction in a vessel when an emergency pressure relief valve opens, or (iii) insufficient vapor space in the vessel for liquid disengagement [26, pp. 14, 18].[a]

The Tank Farm 5 surge drums were horizontal cylindrical vessels, 20 inches in diameter and 96 inches long. During normal operation, there would have been approximately 17 inches of vapor space inside the vessels, but if the Heat Exchanger 5 Surge Drum was experiencing high liquid level at the time of the incident or rapid boiling in the heat exchanger or surge drum, the height and volume available for liquid disengagement could have been much less. In addition, a surge drum with an abnormally high liquid level and temperature would create more turbulence inside, much like a rapidly boiling pot of water on a stove. If an emergency pressure relief valve opened under such circumstances, the pressure inside the surge drum would drop, creating a scenario where rapidly vaporizing ammonia bubbles are forced upward through a saturated liquid, carrying liquid droplets with the bubbles. The concept is illustrated in **Figure 25**.

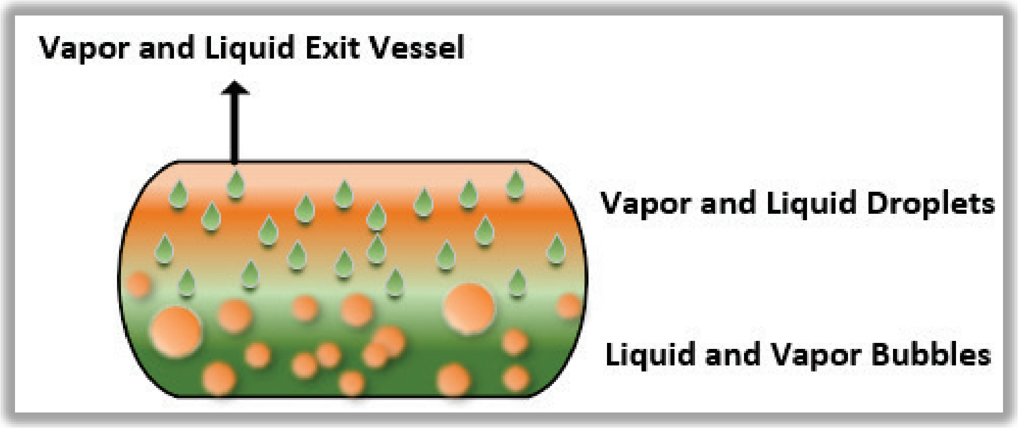


Figure 25: Liquid entrainment in a generalized boiling vessel [28, p. 466]. (Credit: CSB, adapted from *Industrial Refrigeration Handbook*)

The CSB concludes that on the night of the incident, the ammonia release contained liquid aerosol from the Heat Exchanger 5 Surge Drum likely due to either (1) overfilling with boiling liquid, (2) liquid carryover caused by a high liquid level and a sudden pressure drop when the emergency pressure relief valve opened, or (3) insufficient vapor space for liquid disengagement, or a combination of these factors. As a result, the ammonia release, which contained liquid aerosol, allowed IDLH concentrations to reach ground level near the building and evacuation routes.

3.5 Impact of Relief Discharge Piping

In dispersion analysis, there are three variables[b] that are typically important: (i) the velocity of the material as it exits the relief piping, (ii) the discharge piping configuration, such as discharging vertically upward or at an angle or whether discharged through a single pipe or a tee, and (iii) the discharge elevation. These design elements can aid in the dispersion of a toxic release, but with limitations. Other design requirements must still be

[a] An aerosol stream includes liquid droplets as well as vapor [38, p. 2].
[b] These are not the only three variables important in dispersion analysis.

met, such as backpressure limitations for the specific type of emergency pressure relief valve used. Relief discharge piping design must optimize and balance all these variables and requirements.

The dispersion modeling in Appendix D analyzed the effect that changes in discharge piping design could have had on the Sterling plant incident cloud dispersion. The analysis was intended to determine the potential effects on toxic cloud dispersion only, and did not evaluate any other design requirements such as backpressure on relief devices.

Discharge Velocity

In existing ammonia refrigeration systems, emergency pressure relief devices often discharge into a common relief header [26, p. 21], as in the Tank Farm 5 arrangement. This inevitably results in multiple discharge velocities, depending on which devices activate and the piping sizes involved in a given release.

The Tank Farm 5 common relief header discharge was a 3-inch pipe at the tee diffuser. On the night of the incident, the emergency pressure relief valve that opened was a ½-inch inlet and ¾-inch outlet, with a capacity of approximately 9 pounds per minute of ammonia vapor. This combination of lower flow rate and larger discharge pipe means the discharge velocity was low, at approximately 26 to 31 feet per minute (cases 1 and 2 in Appendix D).[a]

In the liquid aerosol release case, increased discharge velocity up to approximately 465 feet per second—or approximately 15 times the actual velocity during the incident—would not have prevented IDLH concentrations of 300 ppm or higher from reaching ground level (case 17 in Appendix D), even if there had been a single vertical discharge instead of a tee, as shown in **Figure 26** below.

[a] This range in discharge velocity reflects the difference in an all-vapor release and a predominantly liquid release. Since the precise liquid content is not known, the velocity range is given. See Appendix D, at page 13, Cases 1 and 2.

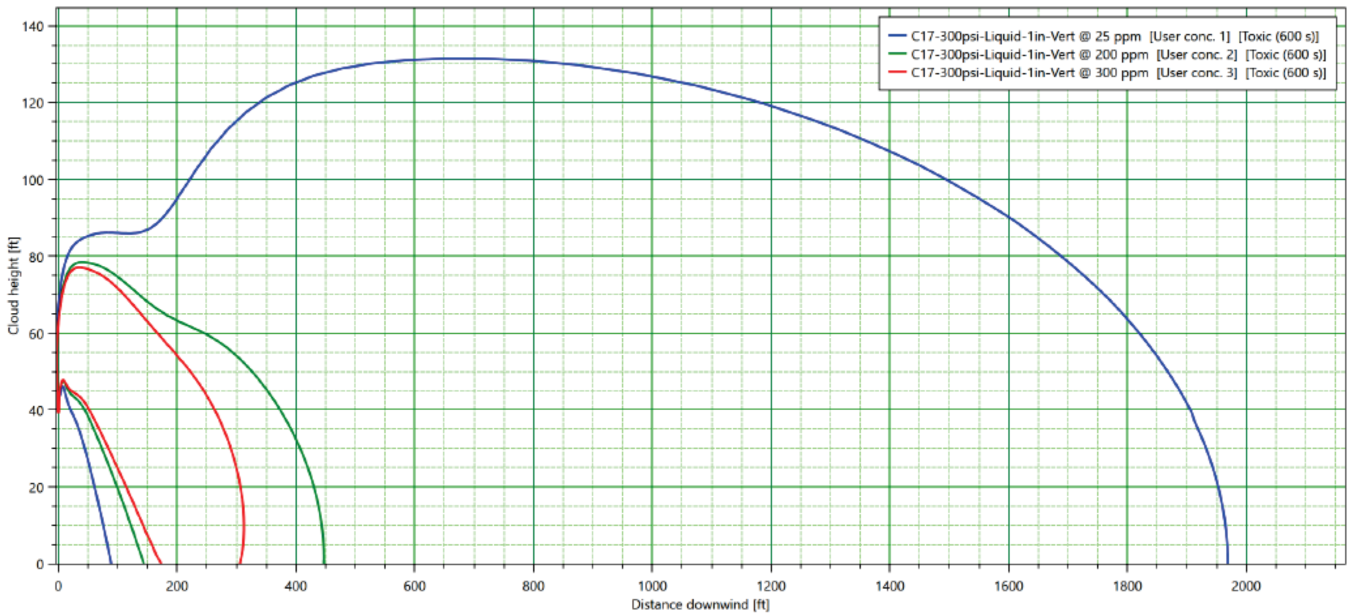


Figure 26: Ammonia release cloud with a 1-inch vertical discharge pipe. With liquid in the discharge, IDLH concentrations (300 ppm, red curve) and toxic endpoint (200 ppm, green curve) could still reach ground level.[a] (Credit: CSB)

Technical Paper #6 estimated the adequate discharge velocity for a 12 weight percent aerosol:

- 250 feet per second is adequate at 10 pounds per minute;
- 500 feet per second is adequate at 100 pounds per minute; and
- 750 feet per second is adequate at 500 and 1,000 pounds per minute [26, p. 31].

In the dispersion modeling for this incident, a higher discharge velocity and a single 1-inch vertical discharge pipe (case 17) improved the cloud dispersion before reaching ground level, compared with the base case 1 in **Figure 21** above. However, in case 17, a cloud at IDLH concentration still reached ground level and could impact evacuees approximately 100 feet or more from the release point. Since the employee entrance doors at the Sterling plant were approximately 128 feet south of the release point, evacuees exiting through that door still could have entered an IDLH cloud during the evacuation, however briefly. While case 17 met the Technical Paper #6 guidelines above for discharge velocity, it also likely had a significantly higher liquid content[b] than that used in Technical Paper #6, and, as such, the cloud still slumped to ground level.

Discharge Piping Configuration

The Tank Farm 5 common relief header terminated in a 3-inch tee diffuser cut at a 60-degree bevel (**Figure 8** above). This configuration likely contributed to the ammonia cloud slumping and reaching the evacuees in several ways:

[a] Case 17 in Appendix D.
[b] Case 17 liquid content was 69 weight percent, while the aerosol modeled in Technical Paper #6 was 12 weight percent liquid.

- The large discharge pipe size relative to the emergency pressure relief valve orifice size limited the velocity of material exiting the relief discharge;
- The split into the 3-inch tee diffuser further reduced the discharge velocity;
- The two horizontal discharges eliminated the upward momentum of material exiting the relief discharge; and
- The 60-degree bevel cut to the horizontal discharge further directed the material exiting the relief discharge downward. This phenomenon is detailed in Appendix D.

Figure 27 below shows the differences modeled between the bevel-cut tee diffuser installed at the time of the incident (blue); other tee diffusers with the ends pointing horizontally (purple), upward at 45 degrees (pink), and vertically upward (light blue); and a single 1-inch discharge with a higher discharge velocity as discussed above (brown). For a relief discharge that contains a significant liquid fraction, the changes in discharge orientation still result in ground-level IDLH ammonia concentrations in all cases.[a] While the vertical single pipe discharge (brown curve in **Figure 27**) showed marginal improvement, half-clouds for the tee diffusers in all orientations are similar.

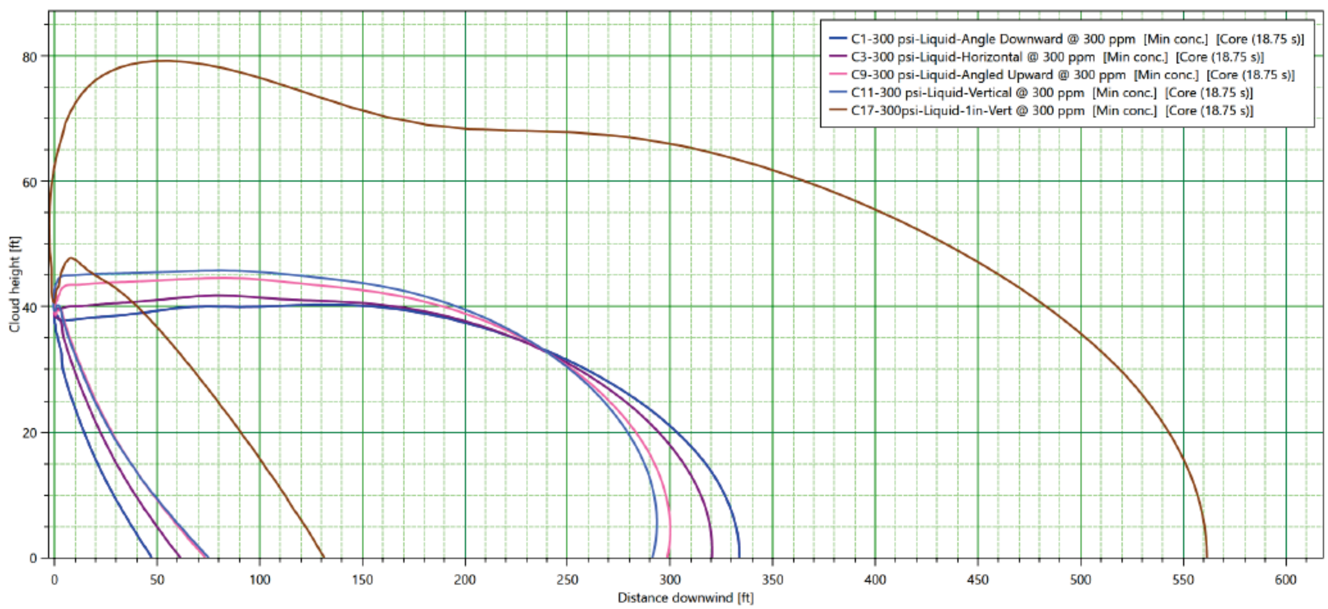


Figure 27: Half-clouds showing 300 ppm curves for four tee diffuser orientations, compared with the entire cloud for a single vertical discharge at higher discharge velocity (brown curve). (Credit: CSB)

<u>Release Elevation</u>

At the time of the incident, the Tank Farm 5 common relief header discharge was approximately 39 feet above the ground, or approximately 15 feet above a 24-foot roof. Even so, much of the ammonia release reached the ground level within seconds, as seen in videos (**Figure 19** above).

[a] See cases 1, 3, 9, 11, and 17 in Appendix D.

All dispersion model runs in Appendix D, except one, were completed at 39 feet above ground level, the same as the actual conditions on the night of the incident. One model run was conducted at 55 feet elevation to determine whether a higher discharge elevation could have reduced the ammonia concentration on the ground during the incident.

The dispersion analysis shows that even if Cuisine Solutions had installed a 1-inch discharge in a vertically upward orientation and at an elevation of 55 feet, a predominantly liquid release would still result in IDLH ammonia concentrations at ground level, although over a smaller area.[a] **Figure 28** compares such a release, with the same weather conditions and entrained liquid, with the model case most like the actual incident ammonia cloud.[b] **Figure 28** shows that discharge piping changes could have marginally mitigated personnel exposure during the incident, but ground-level IDLH concentrations still would have resulted. The original piping configuration resulted in two roughly 300-foot-wide ground-level IDLH clouds (blue curve below is half-cloud), while the improved piping resulted in only one cloud of roughly similar size (purple curve).

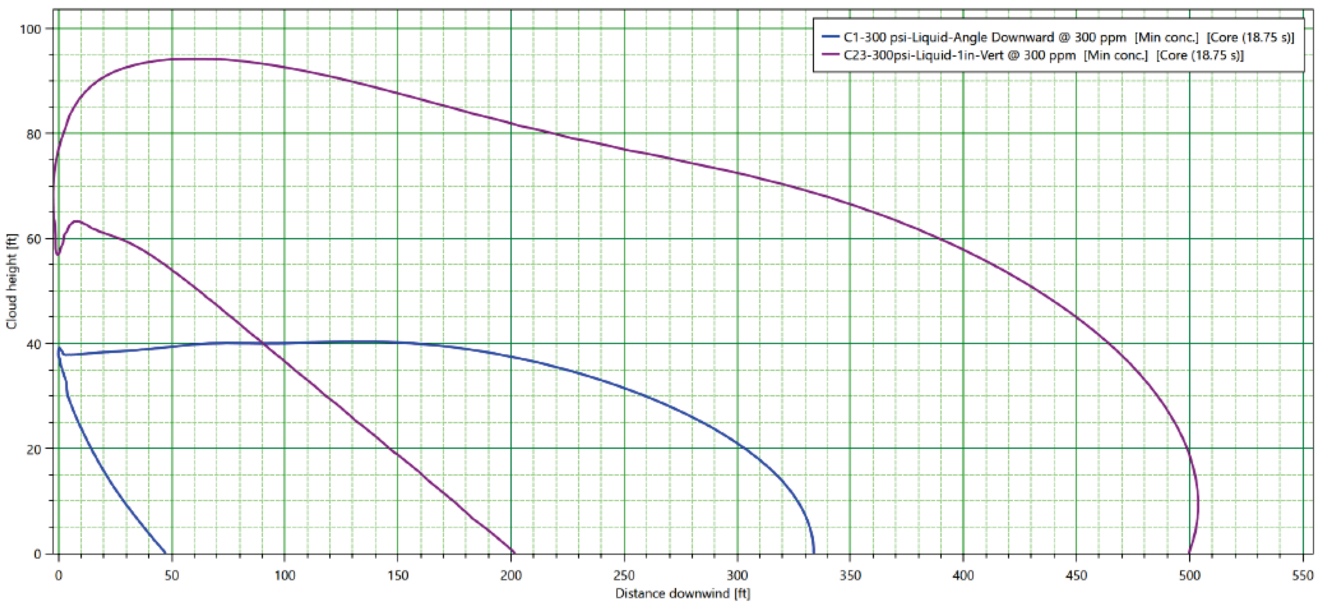


Figure 28: Half-cloud model most like actual release (blue), compared with a similar release, but with improved discharge velocity, orientation, and elevation (full cloud, purple). Curves are for IDLH (300 ppm) concentrations. (Credit: CSB)

The CSB concludes that on the night of the incident, liquid in the relief discharge was the most critical factor in IDLH conditions on the ground, and feasible changes in discharge velocity, orientation, and elevation likely would not have prevented IDLH concentrations from reaching ground level.

Consistent with the dispersion analysis for the Sterling plant ammonia release, Technical Paper #6 predicted that for 12 weight percent liquid aerosols released at 250 feet per second or slower, a discharge elevation from 15 to

[a] As noted above in this section, the dispersion modeling did not consider backpressure requirements for conventional emergency pressure relief valves or other emergency pressure relief valve types. The analysis was intended to determine the potential effects on toxic cloud dispersion only.

[b] Case 23 is the idealized piping case, with a high discharge velocity, a single vertical discharge pipe, and at 55 feet elevation, compared with case 1, the case closest to the actual observed cloud, in Appendix D.

30 to 45 feet indicated "[o]nly a marginal reduction (improvement) in downwind distance" [26, pp. 25-26] as the discharge elevation increased.[a]

The CSB concludes that when liquid is present in the relief discharge, the discharge velocity, a vertical discharge orientation, and a higher elevation can be insufficient to overcome the density of a two-phase ammonia release and to prevent unsafe ammonia concentrations at ground level.

[a] Even for warm vapor releases (77 °F), Technical Paper #6 predicted that "[h]igher discharge elevation does not provide a consistent improvement in downwind distance to 200 PPMV" when the discharge is above 100 pounds per minute [26, p. 29].

4 SAFETY ISSUES

The following sections discuss safety issues contributing to the incident, which include:

- Two-phase Atmospheric Relief
- Discharging to a Safe Location
- Emergency Preparedness

Appendix A contains the accident map (AcciMap), which provides a graphical analysis of this incident.

4.1 TWO-PHASE ATMOSPHERIC RELIEF

The Sterling plant ammonia refrigeration system had emergency pressure relief systems that discharged ammonia to the atmosphere, as discussed above in **Section 1.4**. For Tank Farm 5, the atmospheric discharge vented next to the employee parking lot and the building, which restricted the ability to evacuate personnel safely during the incident. As shown in **Section 3.3**, while this configuration might have been acceptable for a warm vapor release, in relief scenarios involving liquid aerosols or two-phase flow out of the common relief header discharge, it resulted in IDLH ammonia concentrations at ground level.

As discussed in **Section 3.3.4**, at the Sterling plant, the most significant factor in the ammonia cloud's rapid sink rate was the presence of liquid aerosol in the discharge. The sink rate was evidence that the emergency pressure relief valve discharge contained liquid from one or a combination of:

- overfill with liquid in the Heat Exchanger 5 Surge Drum;
- carryover out of the Heat Exchanger 5 Surge Drum relief piping due to high liquid level and a sudden reduction in pressure when the emergency pressure relief valve opened; or
- insufficient vapor space for liquid disengagement (**Section 3.4**).

For ammonia aerosols, Stoecker's *Ammonia Refrigeration Handbook* notes:

> Probably the most treacherous release of ammonia is in aerosol form […]. Tiny droplets of liquid are dispersed throughout the vapor, and the vaporization of this liquid develops a cold, dense combination which usually clings to the ground rather than rising quickly and away from people and vegetation [28, p. 467].

The IIAR's *Refrigeration Piping Handbook* (2019) states that emergency pressure relief discharge and dispersion to the atmosphere is the primary disposal method: "Discharge vapor relief valves to the atmosphere whenever possible; ANSI/IIAR 2 prefers this method" [29, p. 6.14]. The IIAR explains that ammonia vapor discharge to the atmosphere is benign to the environment, and the risks of exposure to high concentrations of released ammonia are very low when relief systems are installed per industry standards and all other code-required measures for controlling system pressures are in place [30]. Thus, it is crucial to prevent liquid and aerosols in emergency pressure relief discharge to the atmosphere.

The phenomenon of liquid overfill or entrainment is not new and has been discussed in ammonia refrigeration publications in the past. However, it has rarely been applied to preventing aerosol relief scenarios in ammonia refrigeration systems [28, pp. 465-466, 31, pp. 304-305, 32, pp. 11, 33-34]. The modeling study in Technical Paper #6 specifically chose a 12 weight percent liquid aerosol release to study, explaining:

> The cold aerosol condition was intentionally selected to ensure the formation of a plume that is initially denser than ambient air, but with insufficient liquid for rainout to occur to form a liquid pool [26, p. 14].

The modeling study in Technical Paper #6 expressly included aerosols to examine mitigating factors for aerosol releases [26, p. 18], which is further discussed below in **Section 4.2.1**. For the Sterling plant release, it is also valuable to consider how the aerosol release could have been prevented in the first place. Preventing an atmospheric release of liquid aerosol likely would have resulted in less severe consequences, even if the emergency pressure relief valve had still activated (**Section 3.3**).

IIAR Technical Paper #9 (2002), *What the Heck Do I Do with My Relief Valves?*, noted the importance of keeping liquid out of a vapor relief discharge, stating:

> Vapor relief connections should be located far enough above the liquid level so that large amounts of liquid ammonia or oil are not drawn out by the vapor flow. How far above is debatable… [31, p. 305]

The possibility of process upsets such as liquid overfill or liquid entrainment in a relief discharge in what might otherwise be vapor-only relief scenarios is known in the refrigeration industry, as well as by the IIAR specifically as shown above. However, ANSI/IIAR 2 does not provide guidance to prevent liquid overfill or entrainment in atmospheric relief scenarios.

Section 15.4.6 of ANSI/IIAR 2, *Standard for Design of Safe Closed-Circuit Ammonia Refrigeration Systems*, prohibits discharging liquid ammonia "into a common relief piping system used to convey ammonia vapor" [13, p. 59], but does not discuss how this is to be accomplished. Section 15.3.3 provides requirements for "pressure vessels intended to operate completely filled with liquid ammonia" [13, p. 53] but does not mention vessels unintentionally filled with liquid. Section 15.3.10 requires that "[p]ressure vessels or any other ASME-stamped piece of equipment expected to operate completely filled with liquid must be equipped with certified pressure relief devices designed for liquid pressure relief per the ASME B&PV Code…" [13, p. 56].

ANSI/IIAR 2 does not discuss any liquid overfill or two-phase relief cases or the potential for liquid in relief cases expected to be vapor-only releases to the atmosphere. Nevertheless, this hazard is common for small horizontal surge drums containing a saturated liquid refrigerant with little vapor space, like the Tank Farm 5 surge drums, as described in **Section 3.4**. Such vessels can fill rapidly with liquid in an upset event and can entrain liquid in the relief discharge when a boiling liquid is inside the vessel, as is frequently the case in refrigeration systems [28, p. 43].

The CSB concludes that ANSI/IIAR 2 does not account for potential liquid overfill, liquid entrainment, or aerosol release relief scenarios, and does not provide users with design guidance or requirements to prevent liquid or aerosol in atmospheric discharges.

As an example of good guidance in relief design, the American Petroleum Institute (API) publishes standard API 521 Seventh Edition (2020), *Pressure-relieving and Depressuring Systems* ("API 521"). API 521 specifies requirements for emergency pressure relief systems, including examining the causes of overpressure, determining relief rates, and "selecting and designing disposal systems, including such component parts as piping, vessels, flares, and vent stacks" [33, p. 1, 34, p. 1].

API 521 includes a section that discusses "Causes of Overpressure and Their Relieving Rates," including overfilling, and a subsection on disposal system design, including disposal to atmosphere, stating,

> The decision to discharge hydrocarbons or other flammable or hazardous vapors to the atmosphere requires careful attention to ensure that disposal can be accomplished without creating a potential hazard or causing other problems, such as the formation of flammable mixtures at grade level or on elevated structures, exposure of personnel to toxic vapors or corrosive chemicals… [34, p. 125]

API 521 further states:

> A PRD [pressure relief device] handling a liquid at vapor-liquid equilibrium or a mixed-phase fluid produces vapor due to flashing as the fluid moves through the device. The vapor generation can reduce the effective mass flow capacity of the valve and should be taken into account. *Liquid carryover can result from foaming or inadequate vapor-liquid disengaging* [emphasis added] [34, p. 78].
>
> Consideration should be given to any phase change, either vaporization of liquid or condensation of vapor, that occurs in the fluid when the pressure is reduced or as a result of cooling. With autorefrigeration, vaporization of volatile liquids can be incomplete unless facilities are provided to add the necessary heat for vaporization [34, p. 80].

Specific to liquids or two-phase releases, API 521 adds that "[a]ll possibilities that can allow liquid to gain entrance to the PRV [pressure relief valve] should be determined and appropriate safeguards should be taken to prevent this occurrence" [34, p. 132].

ANSI/IIAR 2 does not include a complete list of overpressure causes. Although it discusses several scenarios such as external fire, heat exchanger internal loads, hydrostatic overpressure, and positive displacement compressor protection [13, pp. 54-56], it does not discuss other causes of system overpressure like those identified in **Section 3.2** as likely causes at the Sterling plant. Although refrigeration system vessels, such as the Tank Farm 5 Surge Drums, routinely contain saturated liquids, ANSI/IIAR 2 does not provide any warnings or guidance against liquid carryover or inadequate vapor-liquid disengagement, in contrast to API 521.

The CSB concludes that had ANSI/IIAR 2 identified potential scenarios and required an evaluation for potential liquid overfill, liquid entrainment, or aerosol release events, the likelihood of the Sterling plant incident could have been reduced.

The CSB recommends that the IIAR update ANSI/IIAR 2 to include guidance for preventing liquid or two-phase atmospheric discharges from emergency pressure relief systems, such as the guidance in API Standard 521, *Pressure-relieving and Depressuring Systems*. At a minimum, the guidance should:

a. Identify at-risk scenarios such as horizontal surge vessels and other vessels containing saturated liquid with little vapor space; and

b. Address design considerations and controls to reduce the likelihood of identified scenarios leading to overpressure or equipment failure and ensure vapor-liquid disengagement (the separation of vapor from liquid) during pressure relief for identified scenarios.

4.2 Discharging to a Safe Location

In his 1990 book, *Critical Aspects of Safety and Loss Prevention*, Dr. Trevor Kletz cautioned readers to consider what will happen when emergency pressure relief systems function as designed, emphasizing that these safety systems must discharge to a safe location. Kletz forewarned:

> Relief valves are designed to lift and so when they do they should not create a hazard by discharging material over people or plant ... [35, p. 146].

Ensuring no harm to people by confirming that safety systems discharge to a safe location is a fundamental emergency pressure relief system design principle. Thus, a "safe location" can be defined as one that ensures no harm to people.

Typically, multiple potential scenarios could cause high pressure inside industrial refrigeration equipment, and emergency pressure relief system design should address these scenarios. Emergency pressure relief systems not only need to protect equipment, but they must also protect people. It is essential to ensure that employees are aware of when the operating pressure of a system approaches a design limit. Many high-pressure scenarios could occur during a startup, shutdown, or normal operations of an ammonia refrigeration system, where even though refrigeration technicians might not have time to act to prevent an overpressure, the emergency pressure relief system would still activate to protect the equipment. Consequently, to protect people, emergency pressure relief systems must be discharged to a safe location.

The API states that an unsafe location is one that may harm people. API's guidance document, *Process Safety Performance Indicators for the Refining and Petrochemical Industries* (Third Edition, 2021) ("API RP 754"), defines an unsafe (hazardous) location for discharging toxic materials from emergency pressure relief systems as:

> An atmospheric PRD [pressure relief device or emergency pressure relief valve] or upset emission discharge or a downstream destructive device discharge that results in a potential hazard to personnel, whether present or not, due to the formation of flammable mixtures at ground level or on elevated work structures, presence of toxic or corrosive materials at ground level or on elevated work

> structures, or thermal radiation effects at ground level or on elevated work structures from ignition of relief streams at the point of emission as specified in API 521 Section 5.8.4.4 [34, p. 135, 36, p. 10].

The Sterling plant incident shows that the Tank Farm 5 emergency pressure relief system discharge met the API RP 754 criteria for an unsafe location.

4.2.1 MITIGATING A LIQUID OR AEROSOL RELEASE

In emergency pressure relief cases where liquid entrainment or liquid aerosols in relief discharge may not be entirely or reliably preventable, mitigative measures may be required to ensure that liquid ammonia does not reach an atmospheric discharge or cause harm. Preventive controls may not be feasible in some cases, such as for an existing ammonia refrigeration system. Additionally, it may not always be clear whether liquid entrainment, vapor-liquid disengagement, or aerosols will occur based on varying process conditions. Including mitigative measures adds layers of protection against toxic releases to the atmosphere in an emergency pressure relief event.

As discussed above in **Section 4.1**, ANSI/IIAR 2 encourages atmospheric emergency pressure relief discharge whenever possible. Atmospheric relief discharge is a common and economical design, provided it does not create additional hazards [34, p. 125]. For toxic liquids and vapors such as ammonia, this requires careful attention to verify that there is a safe discharge to the atmosphere [34, p. 125], which typically can be done through a dispersion analysis.

ANSI/IIAR 2 sets forth relief discharge piping configuration requirements, discussed further in **Section 4.2.2** below, that are designed to disperse an atmospheric vapor discharge. In Appendix A,[a] Although ANSI/IIAR 2 notes that "[r]elease modeling programs are available to aid in evaluating off-site consequences" [13, p. 90], performing a dispersion analysis is not required and is otherwise not mentioned.

In contrast, API 521provides guidance in Section 5.8.3.1 for safe handling of a toxic vapor discharge, stating, "The design of relief devices vented to the atmosphere shall not expose plant personnel and the public to intolerable risks from toxic vapor discharges" [34, p. 132]. Additionally, Section 5.8.3.1 of API 521 provides guidance for variables to be considered in a dispersion analysis, and it articulates two evaluation approaches: consequence-based and risk-based. API 521 explains:

> In either approach, the user shall establish acceptance criteria for PRD [pressure relief device] discharges of toxic vapor to atmosphere.
>
> If applying a consequence-based approach, then the following shall be applied to PRD discharging toxic vapor to atmosphere.
>
> a) Concentrations of toxic vapors, at the company property line, shall not exceed levels that cause life threatening health effects [e.g. emergency response planning

[a] As discussed above, Appendix material in ANSI/IIAR standards is simply informative, explanatory material and not part of RAGAGEP [13, p. 71].

guideline (ERPG)-3 or equivalent]. Note that life-threatening toxicity values vary greatly for different materials. […]

b) For personnel inside the plant, the ability to escape is a critical factor in determining the exposure limit. For trained personnel, who have an unobstructed escape route, a higher exposure criterion may be used.

If applying a risk-based approach, then a risk assessment [e.g. layer of protection analysis (LOPA), fault tree analysis, etc.] shall be used to determine the suitability of atmospheric discharge.

If either the consequence-based or risk-based approaches indicate a potential for exposure in excess of the acceptance criteria, then one or more of the following mitigations is recommended.

[…]

b) perform a more rigorous evaluation to better estimate the relief load and/or duration (e.g. perform dynamic analysis);

c) modify operating conditions to reduce the sizing basis for the PRV (e.g. reduce upstream pressure to reduce relief load, reduce steam pressure to reach a pinch-point on column reboiler);

d) redesign equipment (e.g. rerate at higher design pressure/MAWP, install a smaller control valve size if control valve failure sets the sizing basis);

e) route the relief device effluent stream back into the process or to a treatment system (e.g. scrubber, flare);

f) modify the atmospheric discharge system to improve dispersion (e.g. taller stack, increased discharge velocity from stack) [34, pp. 132-133].

API 521 further discusses liquid carryover scenarios and consequences:

The siting of vent stacks discharging to atmosphere should consider personnel health and safety, noise, potential odor, *potential ground level concentrations*, *potential liquid carryover*, ignition sources, and thermal radiation [emphasis added]. Dispersion modeling, consequence analysis, and/or risk analysis are valuable tools for evaluating whether vapors discharged from the vent stack pose flammable, toxic, or other hazards to personnel [34, p. 138].

As shown above in **Section 3.3.6**, on the night of the incident, building wake effects likely also contributed to personnel exposure or evacuation delays. Such complex flow considerations should also be considered where applicable [27, p. 35], particularly when they can affect an evacuation, such as at the Sterling site.

Technical Paper #6 recommended that

> Standards and model codes should mandate that the vertical release stacks discharge not only 15 feet above grade or nearby platforms, but *also a minimum height above nearby roofs or walls, to minimize re-entrainment of ammonia vapor in the low-pressure zone to the leeward of such obstacles*… [emphasis added] [26, p. 32].

This recommendation could also address the potential for building wake effects.

The CSB concludes that ANSI/IIAR 2 does not ensure no harm to people for potential liquid overfill, liquid entrainment, or aerosol relief scenarios, and does not provide users with effective guidance and requirements to accurately determine the potential for and consequences of liquid or aerosol in relief discharges.

The CSB recommends that the IIAR update ANSI/IIAR 2 to include a requirement to assess whether emergency pressure relief devices discharge to a safe location, such as with a dispersion analysis.

Even in a relief scenario potentially containing liquid, a liquid or aerosol release can be mitigated through disposal systems or other engineering controls once the potential consequences are well understood through dispersion analysis. While ANSI/IIAR 2 states that emergency pressure relief valves shall discharge vapor directly to the atmosphere [13, p. 59], it allows for exceptions where approved or required by the Authority Having Jurisdiction (AHJ, such as building and fire code officials), including discharge through a treatment system, flaring system, water diffusion system, or other approved means [13, p. 59]. However, some of these systems are not permitted by ANSI/IIAR 2 to receive liquid, such as a water diffusion tank [13, p. 61].

KEY LESSON

Building wake effects and other complex flow considerations should also be evaluated in dispersion analyses where applicable, to ensure a safe discharge to the atmosphere and safe evacuation where necessary.

Many mitigation options exist for cases where liquid may reach the emergency pressure relief valve inlet. A few examples include:

- *Emergency Pressure Control Systems (EPCS)* – Described in ANSI/IIAR 2, Appendix I, these systems relieve an overpressure to another part of the refrigeration system at a slightly lower pressure than the atmospheric emergency pressure relief valve set pressure, redirecting flow within the refrigeration system and averting an atmospheric relief discharge. However, an emergency pressure relief valve is still required, and the part of the system to which the EPCS relieves must be capable of accepting the diverted material without creating unintended hazardous conditions [13, pp. 90, 119].

- *Atmospheric Knockout Drums* – Described in API 521, Section 5.8.7.2, an atmospheric knockout drum is a simple vessel with an open stack to atmosphere, designed to receive emergency pressure relief valve discharges and then "knock out" any liquid droplets to prevent hazardous concentrations from reaching sensitive areas [34, pp. 135-136]. A knockout drum is a simple, economical option for vapor-liquid disengagement before discharging to the atmosphere. A dispersion analysis would still be needed to verify that the vapor release from the knockout drum could not harm people.

- *Automatic Mitigative Controls* – These are control systems that automatically take mitigative action without human intervention. For example, the refrigeration system could be automatically shut down if sensors detected an emergency pressure relief valve activation. While this would not prevent an overpressure, it could minimize the release quantity and consequences.

The CSB described another example of ammonia refrigeration emergency pressure relief systems harming people in the Incident Report[a] for an ammonia refrigeration emergency pressure relief valve discharge that occurred at the Pilgrim's Pride Canton Poultry Processing Facility in Canton, Georgia in January 2022 [37, pp. 21-22]. In that incident, approximately 4,500 pounds of ammonia was released through an emergency pressure relief valve discharge due to a slide valve failure during a compressor startup. Two employees were seriously injured from ammonia inhalation during the evacuation due to the ammonia hovering outside the building [37, p. 21]. As in the incident at the Sterling plant, the relief discharge piping at the Pilgrim's Pride facility did not ensure no harm to evacuees. After the incident, the company rerouted the emergency pressure relief valve's discharge to a vessel containing ammonia [37, pp. 21-22] rather than to the atmosphere.

ANSI/IIAR 2 lists some possibilities for mitigating vapor discharges into the atmosphere such as treatment systems, flaring systems, and water diffusion systems [13, p. 59] but it does not discuss mitigation for cases where liquid or aerosol relief discharges to the atmosphere may occur [13]. ANSI/IIAR 2 currently requires discharging directly to the atmosphere, with exceptions, for vapor relief [13, p. 59], without requiring analysis to demonstrate that such venting is safe and without mitigative efforts to ensure safe atmospheric discharge.

The CSB concludes that ANSI/IIAR 2 does not require safeguards for mitigating a liquid or aerosol release to the atmosphere in relief scenarios and does not provide users with guidance regarding discharging aerosols to a safe location.

The CSB recommends that the IIAR update ANSI/IIAR 2 to include guidance for mitigating liquid or two-phase atmospheric discharges from emergency pressure relief systems, such as the guidance in API Standard 521, *Pressure-relieving and Depressuring Systems*. At a minimum, the guidance should:

a. Identify at-risk scenarios such as horizontal surge vessels and other vessels containing saturated liquid with little vapor space; and

b. Require mitigative safeguards in cases where vapor-liquid disengagement (the separation of vapor from liquid) during pressure relief cannot be reliably ensured. This should also include alternative disposal systems where applicable.

4.2.2 ANSI/IIAR 2 Discharge Piping Guidance

As discussed above in **Section 4.2.1**, ANSI/IIAR 2 does not require mitigative engineering controls, even if liquid or aerosols may not be eliminated from emergency pressure relief valve inlets, and it does not require dispersion analysis to ensure safe atmospheric discharge. Instead, ANSI/IIAR 2 relies on relief discharge piping

[a] This report on the Pilgrim's Pride incident was published in July 2025 as part of Volume III of the CSB's Incident Reports, located at https://www.csb.gov/assets/1/6/Incident_Reports_Volume_3_2025-07-22.pdf.

configuration and location, and it presumes that emergency pressure relief systems will release only vapor to atmosphere.

ANSI/IIAR-2 outlines the following requirements for atmospheric termination of ammonia vapor emergency pressure relief systems:

1. Discharge piping must be sized to prevent excessive back pressure [§15.5.1.1]

2. Relief piping termination must be at least 15 feet above grade and at least 20 feet from openings into a building [§15.5.1.2]

3. Relief piping termination must be at least 7.25 feet above a roof or adjacent platform or roof within 20 horizontal feet of the discharge, whichever is highest [§15.5.1.3 and §15.5.1.4]

4. Termination must be directed upward and arranged to avoid spraying ammonia on persons in the vicinity [§15.5.1.5]

5. Provision for draining moisture from the discharge piping and mitigating entry of rain or snow must be provided [§15.5.1.6 and §15.5.1.7] [13, pp. 60-61]

In addition, Appendix A to ANSI/IIAR 2, which is informative explanatory material only and not part of the standard, states:

> The termination of discharge is considered the final several feet of the relief piping. The vent end point of relief piping may include a design to prevent rain and snow from entering. […] The design at the vent end point may be a "double 45 degree" diffuser, a "bull's horn" diffuser, a "self-closing flapper cap" or a "sock hood cover" [13, p. 89].

Section 3.5 above describes the effects of emergency pressure relief valve piping discharge velocity, orientation, and elevation on ammonia dispersion. Generally, better dispersion will be achieved with higher discharge velocity, vertical upward orientation, and higher elevation. However, these variables alone do not guarantee discharge to a safe location, as demonstrated by the Sterling plant incident, as well as the Pilgrim's Pride incident discussed above in **Section 4.2.1**.

Accurately describing the behavior of toxic releases is important in the design of emergency pressure relief systems [38, p. 6]. For example, a 1990 industry review of good practices for the exit conditions from emergency pressure relief valves found that a discharge velocity of 100 feet per second may not create sufficient dilution of toxic gases to ensure that a hazardous concentration of the gas will not return to ground level [38, p. 2]. For ammonia specifically, Technical Paper #6 noted that for a 12 weight percent liquid aerosol release on the order of 10 pounds per minute, a discharge velocity of approximately 250 feet per second is required to disperse the release into the atmosphere [26, p. 33].[a] By contrast, the Sterling plant discharge velocity on the night of the incident was estimated at 26 to 31 feet per second.[b]

ANSI/IIAR 2 does not mention discharge velocity from an emergency pressure relief valve as a consideration, including in the optional guidance material [13]. While many codes, including ANSI/IIAR 2, have limitations to discharge velocity in the form of limits to permissible backpressure on emergency pressure relief valves, monitoring the discharge velocity might at least predict a potential dispersion safety issue, prompting a dispersion analysis. For example, further analysis or alternative design strategies could be considered based on low discharge velocity. As noted in **Section 3.5**, Technical Paper #6 discussed potential guidelines.

As Technical Paper #6 noted:

> The practice of discharging into a common header system tends to increase the range of flow rates that can be experienced as the relief header discharges to atmosphere. This is often done for economic reasons and to reduce the complexity and number of piping runs within a facility. Combining a great number of relief valves into a single discharge header may result in very low discharge velocity when only one relief valve activates [26, p. 21].

As discussed in **Section 1.4.3**, Tank Farm 5 included 18 emergency pressure relief valves that discharged through a common relief header to the atmosphere. This is not unusual in the refrigeration industry and can be accommodated if the common relief header piping is appropriately sized and discharged to a safe location. Discharge velocity could be used to determine whether certain emergency pressure relief valves should discharge into a common relief header or whether some devices may require a dedicated discharge pipe to ensure that they discharge to a safe location.

An entire section of API 521 is devoted to safely discharging vapors, including hazardous vapors, from emergency pressure relief systems to the atmosphere [33, pp. 144-152, 34, pp. 125-141]. This section is relevant to evaluating the Sterling plant incident because API provides insight as to what industry considers necessary to ensure that emergency pressure relief systems discharge to a safe location. [33, p. 144, 34, p. 125].

[a] The author of Technical Paper #6 also noted: "This is not permission to release liquid ammonia to atmosphere. This recommendation applies to situations where a small mass fraction of liquid may be entrained in venting vapor due to high velocities, boiling, foaming, etc. during release events" [26, p. 33].

[b] This was shown in Appendix D, for cases 1 and 2, on page 13.

Although the ANSI/IIAR 2 discharge piping requirements address atmospheric discharge orientation, location, and elevation, they do not discuss the possibility of a liquid aerosol or droplets in a release. ANSI/IIAR 2 also does not discuss discharge velocity as a potential key factor in ammonia cloud dispersion. For some ammonia releases, the current ANSI/IIAR 2 requirements may not be sufficient to prevent ammonia exposure to bystanders or evacuees in an ammonia relief event.

KEY LESSON

For ammonia refrigeration relief systems, the liquid fraction in an aerosol release, discharge velocity, discharge orientation, and discharge elevation are intricately related and should be studied for any atmospheric relief case to ensure that emergency pressure relief valves discharge to the atmosphere safely.

While ANSI/IIAR 2 relies on relief piping discharge orientation, elevation, and at least 20-foot horizontal distance from building openings to ensure ammonia vapor is discharged to a safe location, the CSB dispersion analysis, the Pilgrim's Pride incident, Technical Paper #6, and other guidance such as API 521 demonstrate that these variables alone do not ensure safe ground-level ammonia concentrations nearby. As discussed above in **Section 3.3.6**, the buoyant portion of the ammonia release at the Sterling plant entered the HVAC unit and allowed ammonia to be pulled into the building, despite the HVAC unit's 20-foot distance from the release point.

The CSB concludes that while ANSI/IIAR 2 contains several requirements for relief discharge orientation, elevation, and location, these requirements may not be sufficient to ensure that ammonia relief streams discharge to a safe location. A dispersion analysis is required to determine the potential impact on evacuation routes and public receptors for atmospheric relief scenarios.

4.2.3 Cuisine Solutions' Discharge Piping

Implementing some preventive measures, such as redesigning or relocating a system, may be challenging for existing ammonia refrigeration systems. Still, engineering controls can be added to any system to prevent an overpressure scenario through improved pressure, temperature, or level controls, for example. Automated mitigative action, rather than relying on human intervention in an emergency, can also be added to refrigeration systems of any age.

After the incident, Cuisine Solutions modified the Sterling plant's emergency pressure relief atmospheric discharge piping by relocating the discharges at Tank Farm 5 and elsewhere, as shown in **Figure 29** below. The changes included moving the discharge away from the nearby HVAC intake and orienting the discharge upward at 45 degrees. The smaller, single pipe discharge (inset in **Figure 29** below) may increase the discharge velocity. These changes meet or exceed the current ANSI/IIAR 2 discharge piping requirements.

Figure 29: Tank Farm 5 atmospheric relief discharge piping, before (left, circled) and after (right, and inset) the incident. (Credit: CSB)

The dispersion analysis of the Sterling plant incident presented above in **Section 3.3** demonstrated that a vertically upward oriented discharge, coupled with a high discharge velocity, could have better dispersed an ammonia release on the night of the incident. However, such discharge piping changes alone likely would have been insufficient to disperse an ammonia release with a high liquid component and prevent ground-level IDLH concentrations, as shown below in **Figure 30**. Although at the time of the incident, the emergency pressure relief piping discharge did not meet all ANSI/IIAR 2 requirements because it did not terminate upwards [13, p. 61],[a] the dispersion modeling indicates that if it had, the results likely would have been similar, given the high liquid content of the ammonia release.[b]

[a] The original piping design was in accordance with the 2014 edition of ANSI/IIAR 2, which also included this requirement [55, p. 61].

[b] Cases 9 and 11 in Appendix D show the ammonia release with a "bullhorn" type tee discharge, oriented 45 degrees upward (case 9) and vertically upward (case 11). Both cases resulted in IDLH concentrations of ammonia (300 ppm) at eye level and toxic endpoint concentrations (200 ppm) at ground level.

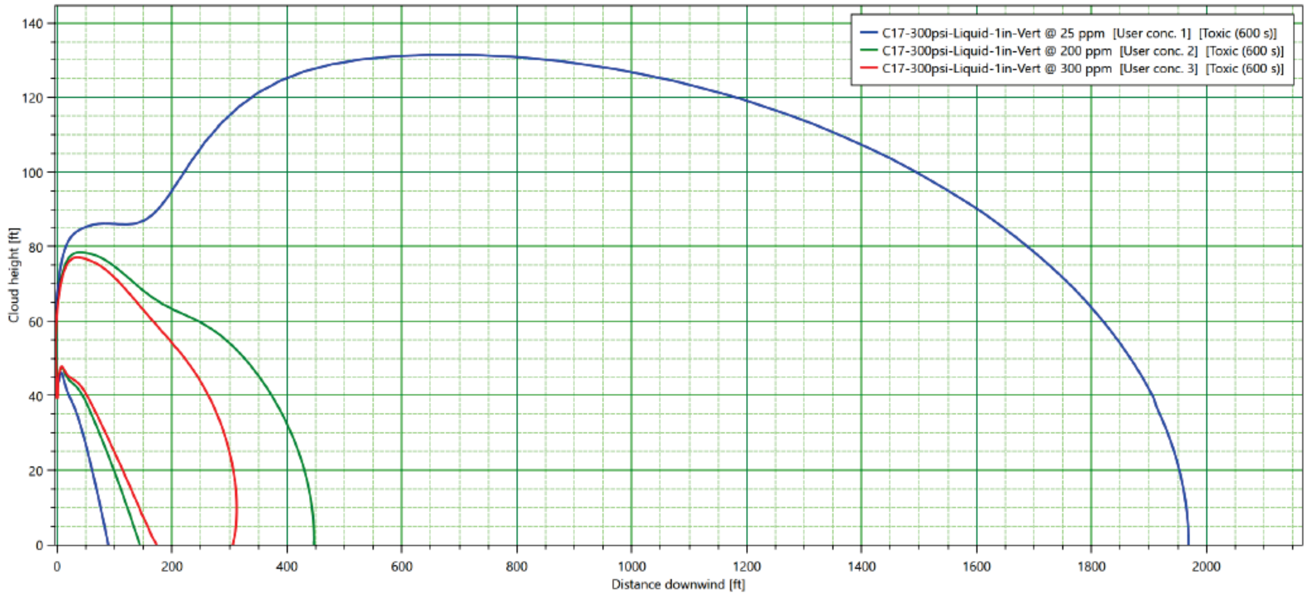


Figure 30: Dispersion model case most like the actual release during the incident, but with 1-inch vertical discharge piping. IDLH concentrations (300 ppm, red curve), as well as the toxic endpoint (200 ppm, green curve), would likely still have reached ground level. (Credit: CSB)

If a process upset similar to the one that occurred at the Sterling plant on July 31, 2024, happened again—particularly in a horizontal vessel such as those at Tank Farm 4 or Tank Farm 5—the liquid or aerosol in the relief discharge could still cause a significant portion of the ammonia cloud to slump to ground level. Based on the dispersion modeling, the release at the Sterling plant still would likely have resulted in ground-level IDLH concentrations, even with a 1-inch single vertical discharge pipe and meeting all atmospheric discharge requirements in ANSI/IIAR 2 as discussed above.

The CSB concludes that the Sterling plant's atmospheric discharge piping design may not be sufficient to mitigate IDLH conditions at ground level and ensure discharging to a safe location. As demonstrated by the incident and the CSB's dispersion analysis, a dispersion analysis is required to determine the potential impact on evacuation routes and public receptors for atmospheric relief scenarios, including liquid or aerosol relief scenarios and building wake effects.

After the incident, Cuisine Solutions added multiple systems to alert personnel of a hazardous atmosphere in several locations around the plant. However, Cuisine Solutions has not addressed the potential for liquid or two-phase relief or implemented any automated safeguards for the potential overpressure scenarios discussed in **Section 3.2**, presumably because IIAR standards do not require it.

In addition, to ensure reliable operation when needed, any safety mitigation systems should also comply with ANSI/IIAR 6, *Standard for Inspection, Testing, and Maintenance of Closed-Circuit Ammonia Refrigeration Systems*. This standard provides "minimum requirements for inspection, testing, and maintenance applicable to safe closed-circuit ammonia refrigeration systems" [19, p. v].

The CSB concludes that Cuisine Solutions did not provide mitigation for liquid or two-phase ammonia relief in Tank Farm 5. Had effective mitigative safeguards existed, Cuisine Solutions might have been able to ensure no harm to people.

The CSB recommends that Cuisine Solutions reduce the likelihood or mitigate the consequences of liquid or two-phase discharges from the ammonia refrigeration emergency pressure relief system at the Sterling plant. At a minimum:

a. Identify liquid or two-phase release scenarios, particularly for horizontal surge drums and other vessels containing saturated liquid with little vapor space;

b. Implement engineering controls to reduce the likelihood of high liquid level, overfill, or boiling, overpressure scenarios; and

c. Implement engineering controls to mitigate the consequences of these scenarios where their likelihood cannot be acceptably reduced, such as through emergency pressure control systems, atmospheric knockout drums, or automatic shutdown systems.

d. Contract a competent third party to audit the pressure relief systems. The audit should ensure that (i) all relevant relief scenarios have been identified, (ii) preventive and mitigative engineering controls adequately address the hazards, and (iii) engineering controls are maintained in such a way that they function properly when required.

As discussed in **Section 3.2**, the Sterling plant did not record historical process data for the ammonia refrigeration system beyond food storage, chiller, or freezer temperatures required for food safety concerns. If a process upset similar to the one that occurred at the Sterling plant on July 31, 2024, happened again, it would likely remain undetected until another overpressure occurred, and a similar incident could happen again. As in this incident, an investigation would likely be unable to determine the specific cause of the overpressure or upset condition without process data.

The CSB concludes that without more extensive refrigeration system process data in a process data historian, the Sterling plant could experience an undetected process upset, similar to the events leading up to the incident. The lack of such process data available for performance monitoring can mask serious process control problems, hamper the investigation of an incident or near miss, and make a repeat incident more likely to occur.

The CSB recommends that the Sterling plant implement an electronic process data historian and management system to ensure that critical process parameters are collected, tracked, and stored. The system should be available to refrigeration technicians so that they can monitor the refrigeration system and respond to and investigate process upsets.

4.3 Emergency Preparedness

Companies that handle hazardous materials such as anhydrous ammonia must consider the possibility of loss of containment, emergency discharges to the atmosphere, or other incidents, such as the Sterling plant incident. OSHA's PSM standard lists emergency planning and response as one of its 14 PSM elements.[a] EPA's RMP rule

[a] 29 C.F.R § 1910.119(n)

also requires emergency planning.[a] Cuisine Solutions was therefore required to define emergency scenarios and develop plans to manage them.

4.3.1 Emergency Action Plan

Facilities such as the Sterling site, with ammonia refrigeration systems that are part of EPA's RMP Process Program - Level 3 (**Section 1.5.2**) and OSHA's PSM standard, must document an Emergency Action Plan (EAP)[b] to address ammonia releases [39, 40]. If a company also intends to respond to an ammonia release, it must also have an Emergency Response Plan[c] that includes required procedures for employees who handle the emergency response [39, p. 3]. Facilities that intend to evacuate their personnel and let external emergency responders manage a chemical release still must develop an EAP [41]. The Sterling site had used an EAP since ammonia was first introduced to the site in 2013, and it had an EAP on the day of the incident.

An effective EAP facilitates and organizes personnel actions during workplace emergencies, reducing the consequences of such events. Minimum EAP requirements include:

- procedures for reporting a fire or other emergency;
- procedures for emergency evacuation, including the type of evacuation and exit route assignments; and
- procedures to be followed by employees who remain to operate critical plant operations before they evacuate.[d]

The IIAR's *Critical Task Guidance for Ammonia Refrigeration System Emergency Planning* (the "Critical Task Guidance"), published in 2021, addresses three critical tasks associated with the response to an unplanned ammonia incident: (i) Preparation, (ii) Escape and System Emergency Control, and (iii) Rescue [42, p. 1]. The Critical Task Guidance is simply informative and is not a mandatory IIAR standard. Instead, the guidance is just "intended to assist employers, government regulators, and public safety emergency responders in preparing emergency procedures to avoid and address ammonia incidents" [42, p. 1].

As part of Critical Task 1, Preparation, the guidance advises that all personnel onsite should "understand the meaning of evacuation terms such as muster, hazardous areas, and lateral/upwind escape path" [42, p. 15]. Training and policies, including these concepts, should be integrated into the facility's EAP ahead of time [42, p. 15].

As part of Critical Task 2, Escape and System Emergency Control, the guidance states that during an evacuation following a chemical release, facility personnel should understand the wind patterns outside the facility and their effects on the escape routes, muster points, and shelter-in-place locations. The guidance further states that it is also important to understand how to escape laterally and upwind of visible clouds and invisible vapors based on eye-level wind conditions [42, p. 16].

[a] 40 C.F.R. § 68.93
[b] 29 C.F.R § 1910.38
[c] 29 C.F.R § 1910.120
[d] 29 C.F.R § 1910.38(c)

Cuisine Solutions' Written Emergency Action Plan

The Sterling site's EAP included an action plan specific to an ammonia release, in addition to other emergency scenarios. The action plan for an ammonia release scenario included several steps:

1. Anyone who notices a suspected chemical release should alert a supervisor or maintenance.
2. Maintenance will "investigate the alleged release."
3. Maintenance will inform the plant or production manager whether the release is classified as small or large.[a]
4. When the plant or production manager agrees that an evacuation is required, they "will use cell phones and voice communication to signal an evacuation is needed."
5. Supervisors will evacuate all personnel to the specified muster point or a secondary muster point if needed.[b]
6. A headcount will be performed, and any missing personnel will be reported to authorities for rescue as needed.

The EAP also stated, "Maintenance technicians may respond only to small releases that do not necessitate an emergency evacuation. All employees and contractors will evacuate at 250 ppm ammonia concentration and the [Loudoun County] HAZMAT team called in."[c]

On the night of the incident, only three to four minutes elapsed from the time an employee first noticed an unidentified odor in the parking lot to when the production manager decided to evacuate. However, the CSB identified several gaps in the EAP as written, and in Cuisine Solutions' emergency planning in general, including: (i) not accounting for wind direction, (ii) not differentiating between indoor and outdoor ammonia releases, (iii) ineffective communication of the decision to evacuate, and (iv) not providing specific procedures for employees to follow before or during evacuation (**Section 4.3.4**).

Wind Direction

The EAP did not include any requirement for workers to check the wind direction to ensure that the evacuation remained upwind of an ammonia release. Instead, the EAP mentioned wind only in relation to weather emergencies. Moreover, there were not enough visible windsocks at the Sterling site to be of any real help at the time of the incident, and workers had not been trained to determine the wind direction during an ammonia release. As discussed above in **Section 3.3**, some workers inhaled ammonia during the evacuation as a result.

After the incident, Cuisine Solutions installed several new windsocks at the Sterling site. However, the CSB found no evidence of any employee training to use them in an ammonia release event. There also were no

[a] The EAP defined small and large releases, but the distinction is not relevant here.

[b] The specified muster point was at the intersection of Sous Vide Lane and Moran Road, as shown below in **Figure 33**. The secondary muster point was at the intersection of Broderick Road and Dresden Street, also shown in **Figure 33**.

[c] The EAP did not specify where the concentration should be measured for this evacuation, but likely inside the building production areas where the ammonia sensors were located, as discussed below in **Section 4.2.3**.

updates to the EAP regarding wind direction or ensuring that personnel remained upwind of a release during evacuation.

Muster Points, Evacuation, and Shelter-in-Place

The Sterling site's EAP included only general directions to evacuate all personnel to a muster point, without specifying a specific evacuation route or giving any consideration to whether any particular evacuation route would remain feasible during an ammonia release. Further, the EAP did not distinguish between different ammonia release situations, such as different hazards presented by an indoor ammonia release as compared with an outdoor one.

The Sterling site was fenced on the east, west, and south sides (represented by gray lines in **Figure 31** below), which restricted available safe upwind evacuation routes during the July 31, 2024 incident. Both designated muster points were to the north of the site, as shown in **Figure 31** below, and were not necessarily suitable for all outdoor ammonia release scenarios. Green arrows in **Figure 31** show typical evacuation routes used. No alternate muster points were designated in the event that these muster points were compromised in an ammonia release. The EAP did not consider sheltering in place as a potential measure to prevent workers from being exposed to the ammonia cloud, nor did the company provide emergency escape respirators or hoods to protect workers from exposure to the cloud while evacuating. On the day of the incident, the designated muster point was generally downwind of the ammonia release, and the evacuation route that many evacuees took was contaminated with ammonia. As a result, some workers inhaled ammonia along the evacuation route, and evacuees continued to walk beyond both designated muster points to avoid the ammonia odor. Some evacuees reported a strong ammonia smell when evacuating, and some stopped or turned back during the evacuation near the northeast corner of the building, as shown in **Figure 31** (red oval).

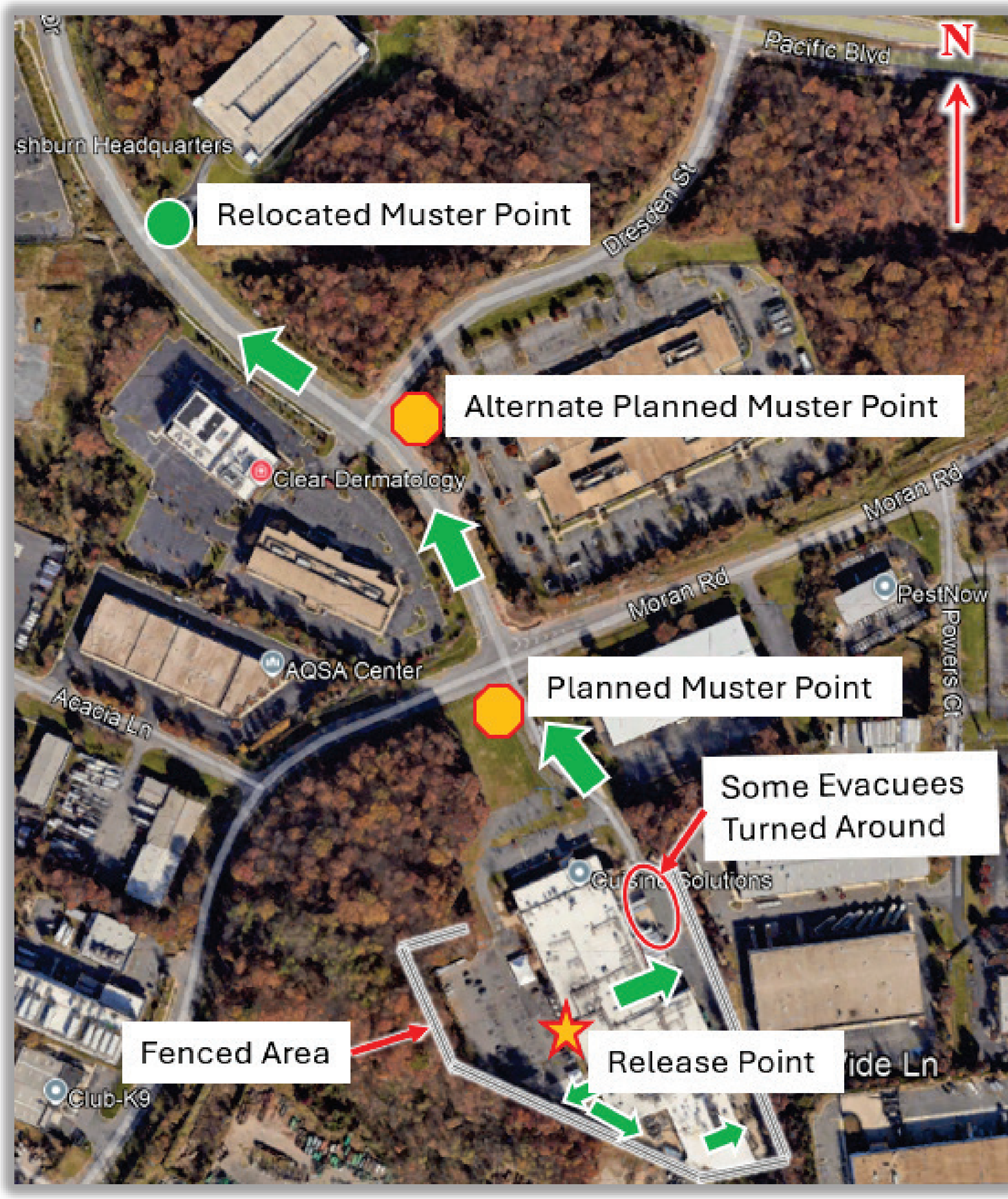


Figure 31: Evacuees moved farther from the site than indicated in the EAP due to the ammonia odor. (Credit: Google Earth, annotated by CSB)

According to evaluations by the Ammonia Safety & Training Institute (ASTI),[a] sheltering in place within a building can be safer than exiting into an ammonia vapor cloud [25, p. 49]. The IIAR's Critical Task Guidance encourages users to assess hazards, risks, and threats in an incident action plan in the Preparation task [42, p. 9]. In addition, the guidance notes that employers may provide escape hoods "to support sheltering in place or…to escape through the IDLH condition to safety" [42, p. 12].

[a] The ASTI is an organization focused on training and emergency response planning related to ammonia safety [47].

As part of Critical Task 2, Escape and System Emergency Control, the IIAR's Critical Task Guidance recommends that training include understanding "the value of escape paths, sheltering in place, muster points, and evacuation staging areas, and of secondary means of egress…" [42, p. 16]. The guidance notes:

> The evacuation rally points, staging areas, and shelter-in-place portion of the program should be reviewed to include locations (if altered or not currently included) and the potential of ammonia to diffuse into locations where people may be present [42, p. 19].

The Sterling site's EAP allowed personnel onsite to be harmed while evacuating. It did not include consideration of safe evacuation in the event of an outdoor ammonia release.

The CSB concludes that the Sterling site's Emergency Action Plan did not follow IIAR guidance and did not adequately address possible ammonia releases outside the building, including alternate evacuation routes and muster points based on wind direction, visible windsocks, adequate distance to ensure muster points are safe, consideration of a possible shelter-in-place strategy, or emergency escape protective equipment for evacuation. As a result, during the incident, some employees evacuated through the ammonia cloud or assembled at the designated muster point too near the release, leading to inhalation of toxic ammonia gas.

Evacuation Communications

OSHA requires facilities with an EAP to maintain an employee alarm system that uses distinctive signals to differentiate between types of emergencies.[a] Although the Sterling site had a fire alarm system, it did not have a specific site-wide evacuation alarm tone for ammonia releases. Instead, the EAP simply directed workers to use "cell phones and voice communications to signal that an evacuation is needed."

On the day of the incident, the production manager at the Sterling plant initiated the evacuation within three to four minutes after an employee initially reported an unknown odor in the parking lot, and within a minute after the ammonia cloud became visible to workers. However, communication through the plant was delayed because there was no site-wide alarm tone to alert all workers at once about an outdoor ammonia release, or alert them of the decision to evacuate the plant. Consequently, many workers were unaware that an ammonia release had

[a] 29 C.F.R § 1910.38(d)

occurred[a] until the release grew into a toxic vapor cloud, or the workers were verbally notified in person that the evacuation process had already started. Rather than being able to communicate the evacuation immediately throughout the plant, as a sitewide alarm would have done, it took fully 10 to 16 minutes to communicate the evacuation throughout the plant. In fact, supervisors and other employees and contractors had to walk room-to-room to communicate the evacuation to their fellow workers, further putting themselves at risk.

Despite making changes to its ammonia sensors and safety systems, the Sterling site did not update its ammonia evacuation procedures in its EAP after the July 31, 2024, incident. To the CSB's knowledge, the Sterling site still lacks a designated evacuation alarm for ammonia releases, and its evacuation procedure still relies on employees' personal cell phones and word of mouth to communicate an evacuation.

The CSB concludes that, although the decision to evacuate was made within a minute of a visible cloud appearing, communicating the evacuation instructions was ineffective, in part because there was no evacuation alarm to alert all employees at once of the evacuation order. Instead, radio and word of mouth communicated news of the evacuation and instructions for where to exit the building. This prolonged the evacuation and caused some evacuees to exit the building in the direction of the release.

KEY LESSON

Distinctive alarms or alarms specific to particular release scenarios allow workers to properly respond to a release quickly. Different release scenarios should be documented in the Emergency Action Plan, and may include multiple distinct alarms and responses, such as one for shelter-in-place and one for evacuation.

The CSB recommends that the Cuisine Solutions Sterling site update its Emergency Action Plan using guidance such as the IIAR's *Critical Task Guidance for Ammonia Refrigeration System Emergency Planning*. At a minimum, the updated plan should:

a. Address indoor and outdoor ammonia releases separately, including the distinct alarms and responses to them;

b. Clearly specify appropriate evacuation routes and muster points, including alternates;

c. Provide guidance for using windsocks to remain upwind of a release during evacuation; and

d. Implement shelter-in-place strategies, emergency protective equipment, and emergency shutdowns, as appropriate.

The CSB recommends that the Cuisine Solutions Sterling site add an alarm or alarms specific to ammonia releases, so that workers can properly respond to a release. Each alarm's distinctive signal should be documented in the updated Emergency Action Plan, and may include multiple distinct alarms and responses, such as one for shelter-in-place and one for evacuation.

[a] As discussed in **Section 2.3**, the production manager directed the evacuation over the radio multiple times, but only some employees had radios.

4.3.2 Emergency Drills

As part of the emergency evacuation procedures, OSHA's PSM standard requires facilities with an EAP to "designate and train employees to assist in a safe and orderly evacuation of other employees"[a] and "review the Emergency Action Plan with each employee covered by the plan."[b] Similarly, EPA's RMP rule requires that Program 3 processes, like the one at the Sterling plant, must conduct an exercise of the emergency response notification mechanisms [43, p. 1].[c] Whether required or not, many facilities conduct emergency drills regularly to ensure that their workers know how to safely evacuate in an emergency [28, p. 470].

The Sterling site's EAP mentioned drills in the "fire prevention plan" portion of the document but it did not call for drills for ammonia releases. Accordingly, the Sterling plant conducted annual fire drills, but it did not conduct emergency drills for indoor or outdoor ammonia releases. As described to CSB investigators by many employees, the fire drills consisted of exiting the building through the nearest exit, assembling all personnel at the flag poles in front of the building (**Figure 32** below)—the identified muster point for a fire—and accounting for all personnel. Cuisine Solutions trained workers to exit the building via the nearest emergency exit door. The fire evacuation plan was also used for smaller or indoor ammonia leaks, but there were no drills specifically focused on ammonia releases. One worker described the drills to the CSB:

> So during the drill, we each have the exit we're supposed to leave through. Depending on the area where you work. And we're told to go over there, to the parking over there where the flags are.
>
> […]
>
> No, the training is not specifically for ammonia. It's for every emergency.

On the day of the incident, the behaviors learned in fire drills were likely repeated based on the previous drills. As a result, multiple workers inhaled toxic ammonia when they evacuated, likely either because of the exit door used or the first muster point, or both. **Figure 32** below shows the locations of the muster points, including the flag poles used in drills.

[a] 29 C.F.R. § 1910.38(e)
[b] 29 C.F.R. § 1910.38(f)
[c] 40 C.F.R. § 68.90(b)(3); 40 C.F.R. § 68.96(a)

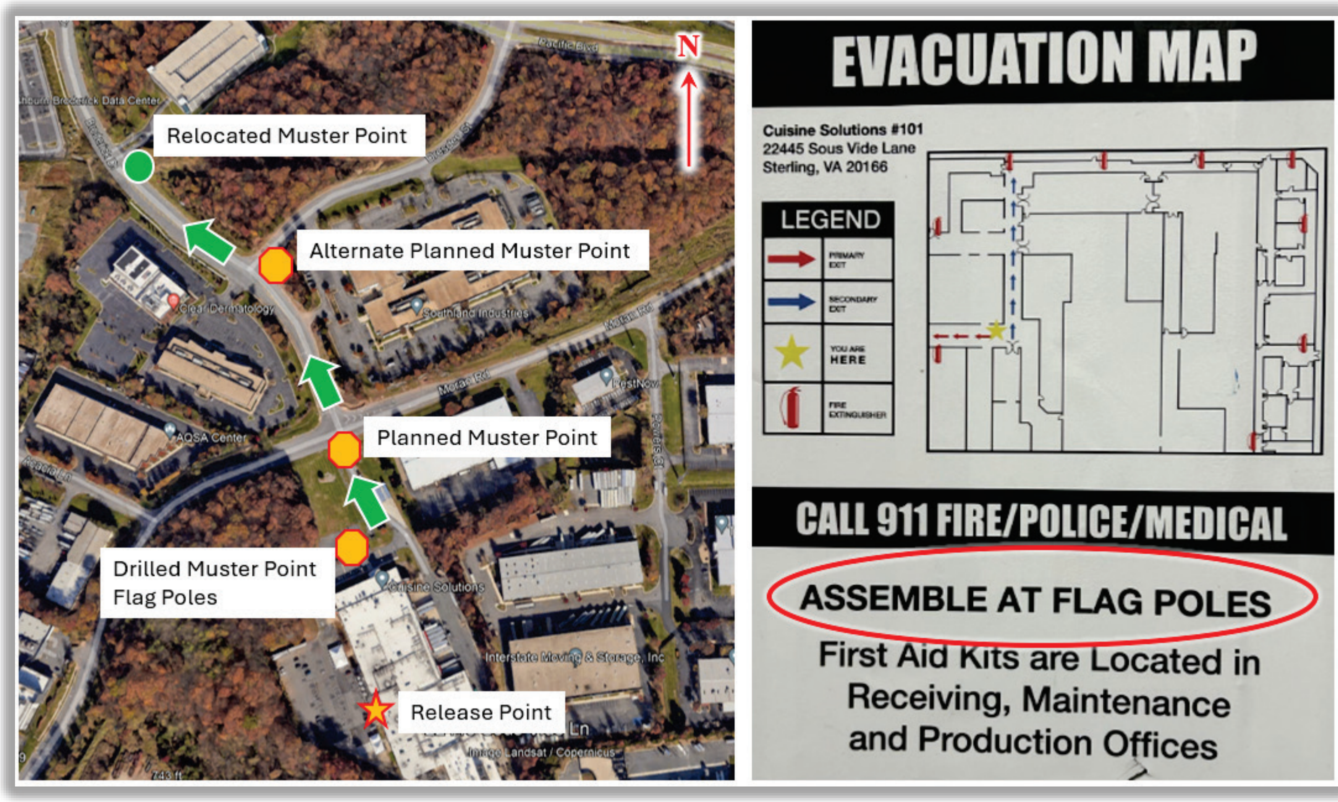


Figure 32: Left, muster point for drills at flag poles, compared with EAP and relocated muster points. Right, an example of evacuation maps in the building. (Left, Credit: Google Earth, annotated by CSB. Right, Credit: CSB)

While the IIAR's Critical Task Guidance does not specifically state that employee evacuation drills are required, it does suggest that employees, contractors, visitors, and bystanders will depend on their training and understanding of how to escape an ammonia release during an emergency [42, p. 11]. The Critical Task Guidance contains lists of numerous items to include in training, such as self-rescue, understanding the ammonia escape plans from all locations within the facility, and how to escape laterally and upwind of an ammonia release [42, pp. 15-16]. Drills are an effective way of ensuring that those onsite during a release recall their training in an emergency.

Locally to the Sterling site, the Loudoun County, Virginia, Local Emergency Planning Committee (LEPC) also provides the following preparedness guidance in its Hazardous Materials Emergency Response Plan:

> Facility owners, operators, and employees should exercise their policies, plans, and procedures, *as well as conduct drills on emergency equipment, skills, and activities* to ensure that everyone potentially involved in the release of a hazardous material is prepared and able to take the appropriate action [emphasis added].

Such guidance should be followed, even if taking appropriate action means a simple evacuation.

The Sterling site did not perform effective emergency drills to prepare its personnel to respond to an outdoor ammonia release. Consequently, some workers remained near or downwind of the release in confusion about where to evacuate during the incident. As discussed above in **Section 4.3.1**, since there were no alternatives to the established muster points in the EAP, such as evacuating upwind of a release or sheltering in place, no drills adequately addressed an ammonia release outside the building.

The CSB concludes that while the Sterling plant's emergency drills addressed a fire at the site, they did not address an ammonia release. During the incident, many evacuees used the nearest exit as they had during drills, in some cases causing them to evacuate through the ammonia cloud.

The CSB recommends that the Cuisine Solutions Sterling site update its Emergency Action Plan using guidance such as the IIAR's *Critical Task Guidance for Ammonia Refrigeration System Emergency Planning*. At a minimum, the updated plan should include requirements to conduct annual ammonia release drills that include all onsite personnel (including corporate employees). The annual drills should include separate indoor and outdoor ammonia release scenarios and address the use of windsocks to assist with determining evacuation routes, alternate evacuation routes, muster points, and consideration for the decision to shelter-in-place. Additionally, the drills should exercise each evacuation alarm and emergency protective equipment where appropriate.

4.3.3 AMMONIA SENSORS AND ALARMS

Cuisine Solutions had installed multiple ammonia sensors at the Sterling plant, both in some common relief headers, such as at Tank Farm 5, and throughout the production areas for leak detection indoors. IIAR standards do not require ammonia sensors in common relief headers such as at Tank Farm 5. Although the sensors were in place at the Sterling plant, the CSB found no documentation indicating what function they served or what the response to these sensors detecting ammonia should be.

Tank Farm 5 Common Relief Header Alarm

As discussed in **Section 1.4.3**, an ammonia sensor was installed in the Tank Farm 5 common relief header to detect ammonia relief events. When this sensor detected high ammonia concentrations, an alarm sounded at the HMI in the refrigeration control room, but there was no planned corrective action in response to this alarm, either by automatic control or in an operating procedure for human intervention.

The refrigeration technician told the CSB that on the night of the incident, he heard the alarm at the HMI after he returned to the plant, while he was in the refrigeration control room. However, when the alarm initially sounded, no one was in the refrigeration control room to hear the alarm or respond to it. In any case, soon after the first employee who smelled ammonia reported it, it became visually obvious that ammonia was coming out of the Tank Farm 5 common relief header. Moreover, by the time the refrigeration technician returned to the plant, he already knew the source of the ammonia release from phone calls. After emergency responders arrived and asked the technician to shut the refrigeration system down, he stopped the compressors. The alarm at the HMI thus was of no value during the incident.

Compressor Room Common Relief Header Alarm and Interlock

Much like the Tank Farm 5 common relief header design, the common relief header in the compressor room, through which all emergency pressure relief valves in that room relieved, also included an ammonia sensor in the relief discharge header. However, this alarm also activated interlocks. If the common relief header ammonia sensor detected 10,000 ppm, the control system automatically stopped all compressors and closed the king valve. No such interlock function existed for Tank Farm 5.

Indoor Ammonia Alarms

The Sterling plant also included 29 sensors near indoor potential ammonia leak sources, such as evaporators and freezers, throughout the production areas.[a] Although some ammonia migrated inside the building, likely through an HVAC intake on the roof near the relief discharge location, none of the sensors inside the building set off any alarms during the incident. Since the break area where workers reported smelling ammonia was separated from the production areas where the ammonia sensors were located, the sensors likely never detected sufficient ammonia to alarm. No one whom the CSB interviewed reported any flashing lights or audible alarms throughout the building on the night of the incident beyond the alarm that the refrigeration technician reported at the HMI panel in the control room.

The 29 indoor ammonia sensors were each designed to activate a local alarm and warning light to alert workers of an indoor ammonia leak. However, no such equipment was configured to alert workers of an ammonia release outside the building. Thus, there were no audible alarms or warning lights to alert workers inside the building to an outdoor release.

The CSB concludes that the Sterling plant did not have local alarms or other audible or visual indication at Tank Farm 5 where the release occurred or at the emergency exit doors adjacent to Tank Farm 5, and that some employees were unaware of the release location and evacuated into the ammonia cloud during the incident.

After the incident, Cuisine Solutions installed additional ammonia sensors at the Sterling plant, including ammonia sensors next to emergency exit doors that activated lights to indicate whether it would be safe to evacuate through the door.

4.3.4 Emergency Shutdown

The Sterling plant had emergency shutdown buttons outside the compressor room. These buttons could remotely shut down the ammonia compressors and close the king valve.

On the day of the incident, the onsite maintenance technician[b] did not shut down the refrigeration system using the emergency shutdown buttons. When the evacuation began, he helped evacuate workers without taking any action related to the ammonia system. When the refrigeration technician returned to the plant, he shut down the compressors individually approximately 25 to 30 minutes after the release began, but he did not close the king valve. On the night of the incident, no one used the emergency shutdown buttons, whose location is shown below in **Figure 33**, although dozens of people walked past these buttons during the evacuation and the buttons were not near the release. Activating the emergency shutdown buttons early in the ammonia release could have

[a] These indoor ammonia sensors were installed in 2019.
[b] The maintenance technician was a backup for the refrigeration technician, who was offsite at a meal break when the incident began.

immediately stopped the compressors and closed the king valve, isolating most of the ammonia inventory from the opening emergency pressure relief valve and limiting the release quantity.

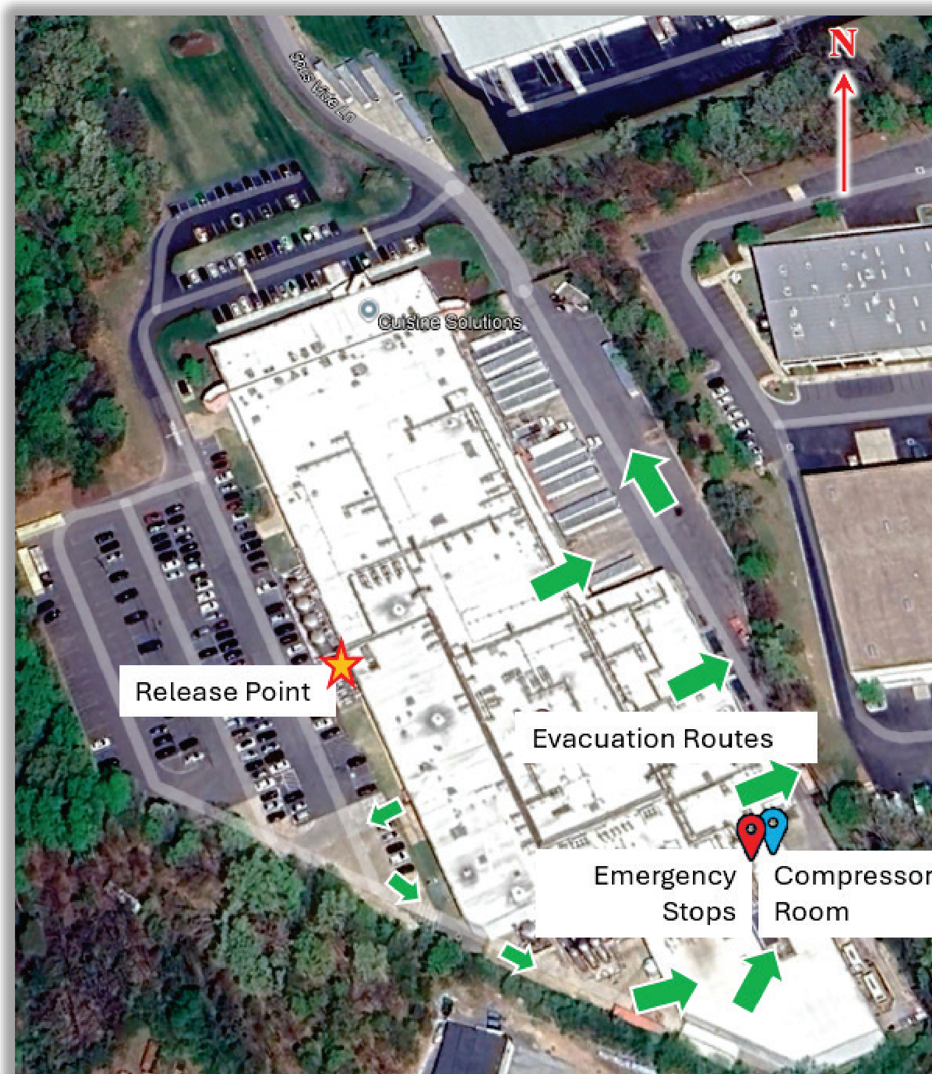


Figure 33: Emergency shutdown buttons (red pin) outside compressor room (blue pin), accessible during the evacuation. (Credit: Google Earth, annotated by CSB)

The CSB was told during interviews with workers that only the refrigeration manager, who worked a day schedule, was trained to use the emergency shutdown buttons. The Sterling site's EAP did not even mention the emergency shutdown buttons. Further, no Sterling plant operating procedures instructed employees when to use the emergency shutdown buttons, although emergency shutdown procedures were available for individual pieces of equipment. The CSB found no evidence that system-wide emergency shutdowns were covered in any training program at the Sterling plant.

OSHA requires workplaces with an EAP to develop "procedures to be followed by employees who remain to operate critical plant operations before they evacuate."[a] Both the OSHA PSM standard and the EPA RMP rule require that operating procedures include "Emergency shutdown including the conditions under which emergency shutdown is required, and the assignment of shutdown responsibility to qualified operators to ensure that emergency shutdown is executed in a safe and timely manner."[b] For facilities that use ammonia refrigeration systems, typical ammonia release emergency procedures include shutting down the compressors and closing the king valve to stop ammonia flow [28, p. 468]. However, the Sterling plant did not provide its workers with operating procedures or training for how or when to use the emergency shutdown buttons.

KEY LESSON

Multiple employees should be trained to perform simple tasks such as using an emergency shutdown device. A well-designed Emergency Action Plan should include simple procedures that backup employees could complete in the event that specialized employees are unavailable or disabled during the emergency. Effective implementation of an Emergency Action Plan should include such items as using the emergency shutdown button if it can be safely accessed, coupled with regular drills to ensure that all personnel onsite clearly understand their duties in an emergency, even if those duties only include safe evacuation.

ANSI/ IIAR 7 (2019), *Developing Operating Procedures for Closed-Circuit Ammonia Refrigeration Systems*, ("ANSI/IIAR 7") requires documenting "steps to operate the safety system under emergency operations, such as when an ammonia release is occurring at the facility" [44, p. 26]. Additionally, in the informative appendix material, ANSI/IIAR 7 recommends developing "emergency shutdown and operating procedures for the entire system, for example, following a large ammonia release…" [44, p. 39].

In the *Critical Task Guidance for Ammonia Refrigeration System Emergency Planning* (2021), the IIAR recommends that, while using an air purifying respirator and under safe conditions:

> A trained operator or technician may assist a victim or *take simple measures to mitigate the release while escaping* [emphasis added]. Such measures are to engage the most appropriate and available means of reducing the impact of an ammonia release, such as the use of ventilation, system shutdown, or other control measures [42, p. 17].

The CSB previously discussed the importance of using an emergency shutdown button to stop ammonia circulation in a refrigeration system in a Safety Bulletin published in 2015, discussing an ammonia release at Millard Refrigerated Services, Inc. in Theodore, Alabama, that occurred in August 2010[c] [45] where three

[a] 29 C.F.R § 1910.38(c)(3); 29 C.F.R. § 1910.119(n)
[b] 29 C.F.R. § 1910.119(f)(1)(i)(D); 40 C.F.R. § 68.69(a)(1)(iv)
[c] The Safety Bulletin is located on the CSB's website at https://www.csb.gov/file.aspx?DocumentId=5933.

employees were exposed while attempting to mitigate the leak instead of activating the emergency shutdown button.

The Sterling plant did not have a system-wide shutdown procedure for the ammonia refrigeration system in the event of an indoor or outdoor ammonia release. Therefore, no workers were trained to activate the emergency shutdown buttons to stop the ammonia system, as recommended by ANSI/IIAR 7 [44, p. 39]. On the night of the incident, using the emergency shutdown buttons early on could have minimized the quantity of ammonia released and reduced the incident's severity. In this case, the emergency stop buttons were easily accessible to personnel as they evacuated as well as before the evacuation even began.

KEY LESSON

Companies should ensure that they fully implement all PSM elements and requirements in their programs, and make sure any gaps are addressed.

The CSB concludes that the Sterling plant did not have an emergency procedure for a system-wide ammonia shutdown and did not include the emergency shutdown buttons in its Emergency Action Plan. As a result, no one onsite was assigned or trained to activate the emergency shutdown buttons on the night of the incident. Had selected personnel been trained to use the emergency shutdown buttons and done so within a few minutes of the release starting, the incident severity could have been reduced.

The CSB makes no recommendation to Cuisine Solutions on this issue because the company is already required to have emergency shutdown procedures in accordance with the PSM standard.[a]

Relying on human intervention is sometimes ineffective, such as at Millard Refrigerated Services and Cuisine Solutions—and as demonstrated in the July 31, 2024 incident at the Sterling plant. People may hesitate to use an emergency shutdown, or they may be unable to reach it in an emergency. For toxic releases, prompt mitigation upon detecting a release is key to mitigating the consequences, and the mitigation is typically faster when automated. To mitigate the hazard in this incident, Cuisine Solutions could have tied in the Tank Farm 5 common relief header ammonia sensor to the emergency shutdown function, automating the emergency shutdown. Since this function already existed for the compressor room common relief header sensor, Cuisine Solutions could have also included the Tank Farm 5 common relief header sensor.

Regardless of any automated mitigative action designed into a refrigeration system, selected personnel should still be trained to safely and manually conduct an emergency shutdown. An automated shutdown can still malfunction, or there could be unanticipated events that do not have a corresponding automated response.

KEY LESSON

Where installed, automated emergency actions can speed the response to a release, thereby minimizing the release quantity and consequences of an ammonia refrigeration system release.

The CSB concludes that the Sterling plant did not have an automated shutdown of the ammonia refrigeration system in the event of an ammonia release, and relied on human intervention, which did not occur during the incident or evacuation.

[a] 29 C.F.R. § 1910.119(f)(1)(i)(D)

The CSB recommends that the Cuisine Solutions Sterling site update its Emergency Action Plan using guidance such as the IIAR's *Critical Task Guidance for Ammonia Refrigeration System Emergency Planning*. At a minimum, the updated plan should:

a. Implement use of emergency shutdowns, as appropriate; and

b. Include requirements to conduct annual ammonia release drills that include all onsite personnel (including corporate employees). The annual drills should include exercise of emergency shutdowns, where appropriate.

5 Conclusions

5.1 Findings

Technical Analysis

1. Although the Tank Farm 5 emergency pressure relief valves were likely beyond the 5-year replacement or testing frequency, failure to test or replace them on time was not causal to the incident.
2. The ammonia release resulted from an emergency pressure relief valve opening on the Heat Exchanger 5 Surge Drum due to an overpressure event, and that the emergency pressure relief valve functioned as designed and intended in this event.
3. The ammonia release resulted from an overpressure event, and a closed or restricted outlet on the Heat Exchanger 5 Surge Drum, combined with a process upset, likely initiated the event. Without process data available for analysis, however, the specific cause of the process upset could not be determined.
4. The ammonia release was not fully vaporized at the discharge to atmosphere because dispersion modeling of a vapor-only release does not fit observations of the ammonia cloud during the incident.
5. The ammonia release contained liquid aerosol, which resulted in a rapidly slumping ammonia cloud that reached ground level. The ground-level cloud likely contained IDLH concentrations of ammonia in areas that workers walked through while evacuating, including outside some of the plant's emergency exit doors.
6. The release quantity was approximately 275 pounds, based on the predicted relief rate for a liquid relief scenario, which most closely represented the actual event.
7. Although the release was on the west side of the building, building wake effects likely contributed to ammonia odors at ground level along the evacuation route on the east side of the building.
8. On the night of the incident, the ammonia release contained liquid aerosol from the Heat Exchanger 5 Surge Drum likely due to either (1) overfilling with boiling liquid, (2) liquid carryover caused by a high liquid level and a sudden pressure drop when the emergency pressure relief valve opened, or (3) insufficient vapor space for liquid disengagement, or a combination of these factors. As a result, the ammonia release, which contained liquid aerosol, allowed IDLH concentrations to reach ground level near the building and evacuation routes.
9. On the night of the incident, liquid in the relief discharge was the most critical factor in IDLH conditions on the ground, and feasible changes in discharge velocity, orientation, and elevation likely would not have prevented IDLH concentrations from reaching ground level.
10. When liquid is present in the relief discharge, the discharge velocity, a vertical discharge orientation, and a higher elevation can be insufficient to overcome the density of a two-phase ammonia release and to prevent unsafe ammonia concentrations at ground level.

Two-phase Atmospheric Relief

11. ANSI/IIAR 2 does not account for potential liquid overfill, liquid entrainment, or aerosol release relief scenarios, and does not provide users with design guidance or requirements to prevent liquid or aerosol in atmospheric discharges

12. Had ANSI/IIAR 2 identified potential scenarios and required an evaluation for potential liquid overfill, liquid entrainment, or aerosol release events, the likelihood of the Sterling plant incident could have been reduced.

Discharging to a Safe Location

13. ANSI/IIAR 2 does not ensure no harm to people for potential liquid overfill, liquid entrainment, or aerosol relief scenarios, and does not provide users with effective guidance and requirements to accurately determine the potential for and consequences of liquid or aerosol in relief discharges.

14. ANSI/IIAR 2 does not require safeguards for mitigating a liquid or aerosol release to the atmosphere in relief scenarios and does not provide users with guidance regarding discharging aerosols to a safe location.

15. While ANSI/IIAR 2 contains several requirements for relief discharge orientation, elevation, and location, these requirements may not be sufficient to ensure that ammonia relief streams discharge to a safe location. A dispersion analysis is required to determine the potential impact on evacuation routes and public receptors for atmospheric relief scenarios.

16. The Sterling plant's atmospheric discharge piping design may not be sufficient to mitigate IDLH conditions at ground level and ensure discharging to a safe location. As demonstrated by the incident and the CSB's dispersion analysis, a dispersion analysis is required to determine the potential impact on evacuation routes and public receptors for atmospheric relief scenarios, including liquid or aerosol relief scenarios and building wake effects.

17. Cuisine Solutions did not provide mitigation for liquid or two-phase ammonia relief in Tank Farm 5. Had effective mitigative safeguards existed, Cuisine Solutions might have been able to ensure no harm to people.

18. Without more extensive refrigeration system process data in a process data historian, the Sterling plant could experience an undetected process upset, similar to the events leading up to the incident. The lack of such process data available for performance monitoring can mask serious process control problems, hamper the investigation of an incident or near miss, and make a repeat incident more likely to occur.

Emergency Preparedness

19. The Sterling site's Emergency Action Plan did not follow IIAR guidance and did not adequately address possible ammonia releases outside the building, including alternate evacuation routes and muster points based on wind direction, visible windsocks, adequate distance to ensure muster points are safe, consideration of a possible shelter-in-place strategy, or emergency escape protective equipment for evacuation. As a result, during the incident, some employees evacuated through the ammonia cloud or

assembled at the designated muster point too near the release, leading to inhalation of toxic ammonia gas.

20. Although the decision to evacuate was made within a minute of a visible cloud appearing, communicating the evacuation instructions was ineffective, in part because there was no evacuation alarm to alert all employees at once of the evacuation order. Instead, radio and word of mouth communicated news of the evacuation and instructions for where to exit the building. This prolonged the evacuation and caused some evacuees to exit the building in the direction of the release.

21. While the Sterling plant's emergency drills addressed a fire at the site, they did not address an ammonia release. During the incident, many evacuees used the nearest exit as they had during drills, in some cases causing them to evacuate through the ammonia cloud.

22. The Sterling plant did not have local alarms or other audible or visual indication at Tank Farm 5 where the release occurred or at the emergency exit doors adjacent to Tank Farm 5, and some employees were unaware of the release location and evacuated into the ammonia cloud during the incident.

23. The Sterling plant did not have an emergency procedure for a system-wide ammonia shutdown and did not include the emergency shutdown buttons in its Emergency Action Plan. As a result, no one onsite was assigned or trained to activate the emergency shutdown buttons on the night of the incident. Had selected personnel been trained to use the emergency shutdown buttons and done so within a few minutes of the release starting, the incident severity could have been reduced.

24. The Sterling plant did not have an automated shutdown of the ammonia refrigeration system in the event of an ammonia release, and relied on human intervention, which did not occur during the incident or evacuation.

5.2 Cause

The CSB determined that the cause of the incident was an overpressure in a vessel that released a toxic ammonia cloud through an emergency pressure relief valve that opened near the employee parking lot. The ammonia cloud contained a significant liquid component, which caused much of it to rapidly drop to ground level, exposing workers while they evacuated.

Contributing to the incident was a failure to discharge this emergency pressure relief valve to a safe location and a lack of engineering or administrative controls, such as an automated emergency refrigeration system shutdown, that could have minimized liquid or aerosol in the ammonia release.

The Cuisine Solutions Sterling plant's insufficient emergency preparedness, including the site Emergency Action Plan which did not ensure workers could safely evacuate in the event of an outdoor ammonia release, a lack of effective drills, and a lack of effective emergency shutdown, contributed to the severity of the incident.

6 RECOMMENDATIONS

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB makes the following safety recommendations:

6.1 INTERNATIONAL INSTITUTE OF ALL-NATURAL REFRIGERATION (IIAR)

2024-03-I-VA-R1

Update ANSI/IIAR 2 to include guidance for preventing or mitigating liquid or two-phase atmospheric discharges from emergency pressure relief systems, such as the guidance in API Standard 521, *Pressure-relieving and Depressuring Systems*. At a minimum, the guidance should:

a. Identify at-risk scenarios such as horizontal surge vessels and other vessels containing saturated liquid with little vapor space;

b. Address design considerations and controls to reduce the likelihood of identified scenarios leading to overpressure or equipment failure and ensure vapor-liquid disengagement (the separation of vapor from liquid) during pressure relief for identified scenarios; and

c. Require mitigative safeguards in cases where vapor-liquid disengagement during pressure relief cannot be reliably ensured. This should also include alternative disposal systems where applicable.

2024-03-I-VA-R2

Update ANSI/IIAR 2 to include a requirement to assess whether emergency pressure relief devices discharge to a safe location, such as with a dispersion analysis.

6.2 CUISINE SOLUTIONS, INC., STERLING SITE

2024-03-I-VA-R3

Reduce the likelihood or mitigate the consequences of liquid or two-phase atmospheric discharges from the ammonia refrigeration emergency pressure relief system at the Sterling plant. At a minimum:

a. Identify liquid or two-phase release scenarios, particularly for horizontal surge drums and other vessels containing saturated liquid with little vapor space;

b. Implement engineering controls to reduce the likelihood of high liquid level, overfill, or boiling overpressure scenarios; and

c. Implement engineering controls to mitigate the consequences of these scenarios where their likelihood cannot be acceptably reduced, such as through emergency pressure control systems, atmospheric knockout drums, or automatic shutdown systems.

d. Contract a competent third party to audit the pressure relief systems. The audit should ensure that (i) all relevant relief scenarios have been identified, (ii) preventive and mitigative engineering controls adequately address the hazards, and (iii) engineering controls are maintained in such a way that they function properly when required.

2024-03-I-VA-R4

Implement an electronic process data historian and management system to ensure that critical process parameters are collected, tracked, and stored. The system should be available to refrigeration technicians so that they can monitor the refrigeration system and respond to and investigate process upsets.

2024-03-I-VA-R5

Update the Cuisine Solutions Sterling site's Emergency Action Plan using guidance such as the IIAR's *Critical Task Guidance for Ammonia Refrigeration System Emergency Planning*. At a minimum, the updated plan should:

a. Address indoor and outdoor ammonia releases separately, including the distinct alarms and responses to them;

b. Clearly specify appropriate evacuation routes and muster points, including alternates;

c. Provide guidance for using windsocks to remain upwind of a release during evacuation;

d. Implement shelter-in-place strategies, emergency protective equipment, and emergency shutdowns, as appropriate; and

e. Include requirements to conduct annual ammonia release drills that include all onsite personnel (including corporate employees). The annual drills should include separate indoor and outdoor ammonia release scenarios and address the use of windsocks to assist with determining evacuation routes, alternate evacuation routes, muster points, and consideration for the decision to shelter-in-place. Additionally, the drills should exercise each evacuation alarm, emergency protective equipment, and emergency shutdowns, where appropriate.

2024-03-I-VA-R6

Add an alarm or alarms specific to ammonia releases, so that workers can properly respond to a release. Each alarm's distinctive signal should be documented in the updated Emergency Action Plan, and may include multiple distinct alarms and responses, such as one for shelter-in-place and one for evacuation.

7 KEY LESSONS FOR THE INDUSTRY

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB urges companies to review these key lessons:

1. Companies should ensure that they measure and store process data so that when an incident or process upset occurs, they can analyze the data, determine the causes, and make changes to stop the upset or prevent another incident. The inability to access such process data can mask serious process control problems. Employees cannot respond to a process upset or prevent future ones if they cannot see how a process upset developed. Investigating an incident without sufficient process data hampers investigation and makes a repeat incident more likely to occur.

2. While a dispersion analysis does not relate the visible cloud to the toxic cloud, the analysis, when paired with a video of the visible cloud, clearly shows that much of a toxic ammonia cloud can also be invisible. DO NOT approach an ammonia cloud without proper personal protective equipment (PPE).

3. Building wake effects and other complex flow considerations should also be evaluated in dispersion analyses where applicable, to ensure a safe discharge to the atmosphere and safe evacuation where necessary.

4. For ammonia refrigeration relief systems, the liquid fraction in an aerosol release, discharge velocity, discharge orientation, and discharge elevation are intricately related and should be studied for any atmospheric relief case to ensure that emergency pressure relief valves discharge to the atmosphere safely.

5. Distinctive alarms or alarms specific to particular release scenarios allow workers to properly respond to a release quickly. Different release scenarios should be documented in the Emergency Action Plan, and may include multiple distinct alarms and responses, such as one for shelter-in-place and one for evacuation.

6. Multiple employees should be trained to perform simple tasks such as using an emergency shutdown device. A well-designed Emergency Action Plan should include simple procedures that backup employees could complete in the event that specialized employees are unavailable or disabled during the emergency. Effective implementation of an Emergency Action Plan should include such items as using the emergency shutdown button if it can be safely accessed, coupled with regular drills to ensure that all personnel onsite clearly understand their duties in an emergency, even if those duties only include safe evacuation.

7. Companies should ensure that they fully implement all PSM elements and requirements in their programs, and make sure any gaps are addressed.

8. Where installed, automated emergency actions can speed the response to a release, thereby minimizing the release quantity and consequences of an ammonia refrigeration system release.

8 REFERENCES

[1] Cuisine Solutions, Inc., "About Cuisine Solutions," 2024. [Online]. Available: https://mycuisinesolutions.com/pages/about-cuisine-solutions. [Accessed 26 September 2024].

[2] Cuisine Solutions, Inc., "Industries We Serve," Cuisine Solutions, 2024. [Online]. Available: https://cuisinesolutions.com/industry/?. [Accessed 27 September 2024].

[3] Cuisine Solutions, Inc., "Our Global Presence," Cuisine Solutions, 2024. [Online]. Available: https://cuisinesolutions.com/our-global-presence/. [Accessed 26 September 2024].

[4] U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), "Occupational Safety and Health Administration | Ammonia Refrigeration | Properties of Ammonia," [Online]. Available: https://www.osha.gov/etools/ammonia-refrigeration/ammonia. [Accessed 14 October 2024].

[5] U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), "Occupational Safety and Health Administration | Ammonia Refrigeration Overview," [Online]. Available: https://www.osha.gov/ammonia-refrigeration. [Accessed 28 September 2024].

[6] Tanner Industries, Inc., "Anhydrous Ammonia: (SDS) Safety Data Sheet," 19 January 2023. [Online]. Available: https://tannerind.com/anhydrous-sds.html. [Accessed 26 September 2024].

[7] U.S. Environmental Protection Agency (EPA) Region 7, "Accident Prevention and Response Manual for Anhydrous Ammonia Refrigeration System Operators," June 2015. [Online]. Available: https://www.epa.gov/rmp/accident-prevention-and-response-manual-anhydrous-ammonia-refrigeration-system-operators. [Accessed 27 September 2024].

[8] P. J. Fellows, "Food Processing Technology - Principles and Practice (5th Edition)," Elsevier, 2022.

[9] American Society of Mechanical Engineers (ASME), "Section VIII Rules for Construction of Pressure Vessels," in *2021 ASME Boiler and Pressure Vessel Code - An International Code*, New York, 2021, p. 94.

[10] U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), "Final Rule on Process Safety Management of Highly Hazardous Chemicals; Explosives and Blasting Agents," 26 May 1992. [Online]. Available: https://www.osha.gov/laws-regs/federalregister/1992-02-24. [Accessed 15 March 2025].

[11] U.S. Environmental Protection Agency (EPA), "Risk Management Program (RMP) Rule Overview," USEPA, 10 July 2024. [Online]. Available: https://www.epa.gov/rmp/risk-management-program-rmp-rule-overview. [Accessed 15 March 2025].

[12] U.S. Environmental Protection Agency (EPA), "General RMP Guidance - Chapter 2: Applicability of Program Levels," April 2004. [Online]. Available: https://www.epa.gov/rmp/general-rmp-guidance-chapter-2-applicability-program-levels. [Accessed 15 March 2025].

[13] International Institute of Ammonia Refrigeration (IIAR), "ANSI/IIAR 2-2021 Standard for Design of Safe Closed-Circuit Ammonia Refrigeration Systems," IIAR, Alexandria, Virginia, 2021.

[14] The IIAR Condenser, "International Fire Code to Defer to IIAR for Ammonia Issues," August 2021. [Online]. Available: https://iiarcondenser.org/international-fire-code-to-defer-to-iiar-for-ammonia-issues/. [Accessed 22 April 2025].

[15] U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), "Ammonia Refrigeration - Standards," [Online]. Available: https://www.osha.gov/ammonia-refrigeration/standards. [Accessed 28 February 2025].

[16] Loudoun County Virginia Combined Fire & Rescue System, "News and Announcements," 1 August 2024. [Online]. Available: https://www.loudoun.gov/civicalerts.aspx?aid=9269. [Accessed 16 January 2025].

[17] WTVR-TV, "Ammonia leak at Virginia food plant sends 33 workers to hospitals," 1 August 2024. [Online]. Available: https://www.wtvr.com/news/local-news/cuisine-solutions-ammonia-leak-hospitalizations-aug-1-2024. [Accessed 25 January 2025].

[18] International Institute of Ammonia Refrigeration (IIAR), "Ammonia Data Book," IIAR, Alexandria, Virginia, 2008.

[19] International Institute of Ammonia Refrigeration (IIAR), "ANSI/IIAR 6-2019 Standard for Inspection, Testing, and Maintenance of Closed-Circuit Ammonia Refrigeration Systems," IIAR, Alexandria, Virginia, 2019.

[20] Industrial Refrigeration Consortium (IRC), "Engineering Safety Relief Systems," University of Wisconsin-Madison, Madison, WI, 2006.

[21] Cyrus Shank Company, "Cyrus Shank Company Product Catalog; Relief Valves, Manifolds, Hand Valves," August 2013. [Online]. Available: https://www.cyrusshank.com/shop/. [Accessed 2 June 2025].

[22] Mary Kay O'Connor Process Safety Center, "Dispersion Analysis," Texas A&M Engineering Experiment Station, 2025. [Online]. Available: https://psc.tamu.edu/research/consequence-analysis/. [Accessed 26 May 2025].

[23] R. Benintendi, Process Safety Calculations, Second Edition, Amsterdam: Elsevier, 2021.

[24] U.S. Environmental Protection Agency (EPA), "General RMP Guidance - Appendix E: Supplemental Risk Management Program Guidance for Ammonia Refrigeration Facilities," May 2004. [Online]. Available: https://www.epa.gov/rmp/general-rmp-guidance-appendix-e-supplemental-risk-management-program-guidance-ammonia. [Accessed 1 October 2024].

[25] Ammonia Safety and Training Institute (ASTI), "Cooperative Research and Development Agreement (CRADA) between Chemical Security Analysis Center (CSAC) and Ammonia Safety and Training Institute (ASTI)," Ammonia Safety and Training Institute (ASTI), 2024.

[26] M. L. Timm, "Modeling of Releases from Ammonia Refrigeration Pressure Relief Valves Using Dispersion Modeling Software," in *2014 Industrial Refrigeration Conference & Heavy Equipment Show*, Nashville, 2014.

[27] G. E. DeVaull, J. A. King, R. J. Lantzy and D. J. Fontaine, Understanding Atmospheric Dispersion of Accidental Releases, New York: American Institute of Chemical Engineers, 1995.

[28] W. F. Stoecker, Industrial Refrigeration Handbook, McGraw-Hill, 1998.

[29] International Institute of Ammonia Refrigeration (IIAR), Refrigeration Piping Handbook, Alexandria, Virginia: IIAR, 2019.

[30] Resource Compliance, "Resource Compliance: Update on Ammonia Diffusion Tanks," 5 September 2017. [Online]. Available: https://resourcecompliance.com/wp-content/uploads/2017/03/Position-letter-on-California-Mechanical-Code-re-flaring.pdf. [Accessed 21 April 2025].

[31] L. S. Bonebrake and D. R. Kuespert, "What the Heck Do I Do with My Relief Valves?," in *2002 Ammonia Refrigeration Conference*, Kansas City, MO, 2002.

[32] T. B. Jekel and D. T. Reindl, "Application and Considerations for Internal Relief in Industrial Refrigeration Systems," in *IIAR Natural Refrigeration Conference & Heavy Equipment Expo*, Orlando, 2024.

[33] American Petroleum Institute (API), "API Standard 521, Pressure-Relieving and Depressuring Systems, 6th edition," 2014.

[34] American Petroleum Institute (API), "API Standard 521, Pressure-Relieving and Depressuring Systems, Seventh Edition," 2020.

[35] T. A. Kletz, Critical Aspects of Safety and Loss Prevention, London: Butterworths, 1990.

[36] American Petroleum Institute (API), "Process Safety Performance Indicators for the Refining and Petrochemical Industries: API Recommended Practice 754: Third Edition, August 2021," 2021.

[37] U.S. Chemical Safety and Hazard Investigation Board (CSB), "Volume III of CSB Incident Reports," 22 July 2025. [Online]. Available: https://www.csb.gov/assets/1/6/Incident_Reports_Volume_3_2025-07-22.pdf. [Accessed 25 August 2025].

[38] J. B. Cornwell, D. W. Johnson and W. E. Martinsen, "Relief Valves and Vents: How Exit Conditions Affect Hazard Zones," 19-22 August 1990. [Online]. Available: https://www.questconsult.com/papers/relief-valves-vents/. [Accessed 7 February 2025].

[39] S. T. Maher, M. G. Monge, K. M. Hall and R. S. Adams, "Ammonia Refrigeration System Emergency Action Plans vs. Emergency Response Plans," [Online]. Available: https://archive.ammonia21.com/files/ammonia-emergency-action-response-plans.pdf. [Accessed 25 April 2025].

[40] U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), "Emergency Planning and Response - PSM & RMP 3".

[41] Integrated Solutions, Inc., "What’s the Difference Between the HAZWOPER’s Emergency Response Plan and an Emergency Action Plan?," 18 March 2024. [Online]. Available: https://isienvironmental.com/hazwoper-response-emergency-action-plan-blog/. [Accessed 25 April 2025].

[42] International Institute of Ammonia Refrigeration (IIAR), Critical Task Guidance for Ammonia Refrigeration System Emergency Planning, 1st ed., Alexandria, Virginia: IIAR, 2021.

[43] U.S. Environmental Protection Agency (EPA), "General RMP Guidance - Chapter 8: Emergency Response," December 2021. [Online]. Available: https://www.epa.gov/rmp/general-rmp-guidance-chapter-8-emergency-response-program. [Accessed 9 May 2025].

[44] International Institute of Ammonia Refrigeration (IIAR), ANSI/IIAR 7-2019 - Developing Operating Procedures for Closed-Circuit Ammonia Refrigeration Systems, Alexandria, Virginia: International Institute of Ammonia Refrigeration, 2019.

[45] U.S. Chemical Safety and Hazard Investigation Board (CSB), "Key Lessons for Preventing Hydraulic Shock Anhydrous Ammonia Release at Millard Refrigerated Services, Inc.," 15 January 2015. [Online]. Available: https://www.csb.gov/file.aspx?DocumentId=5933. [Accessed 8 May 2025].

[46] National Board Inspection Code (NBIC), "Part 4: Pressure Relief Devices | 2021," 2021.

[47] Ammonia Safety & Training Institute (ASTI), "About Us," [Online]. Available: https://ammonia-safety.com/about-us-2. [Accessed 21 April 2025].

[48] National Board of Boiler and Pressure Vessel Inspectors (NBBI), "VR Certificate of Authorization," The National Board of Boiler and Pressure Vessel Inspectors, 2025. [Online]. Available: https://www.nationalboard.org/index.aspx?pageID=115&ID=161. [Accessed 2 June 2025].

[49] U.S. Centers for Disease Control and Prevention, "National Institute for Occupational Safety and Health (NIOSH)," U.S. Centers for Disease Control and Prevention, 17 January 2024. [Online]. Available: https://www.cdc.gov/niosh/about/index.html. [Accessed 26 May 2025].

[50] Census Reporter, "Census Reporter," [Online]. Available: https://censusreporter.org/. [Accessed 29 October 2024].

[51] Census Reporter, "About Census Reporter," [Online]. Available: https://censusreporter.org/about/. [Accessed 29 October 2024].

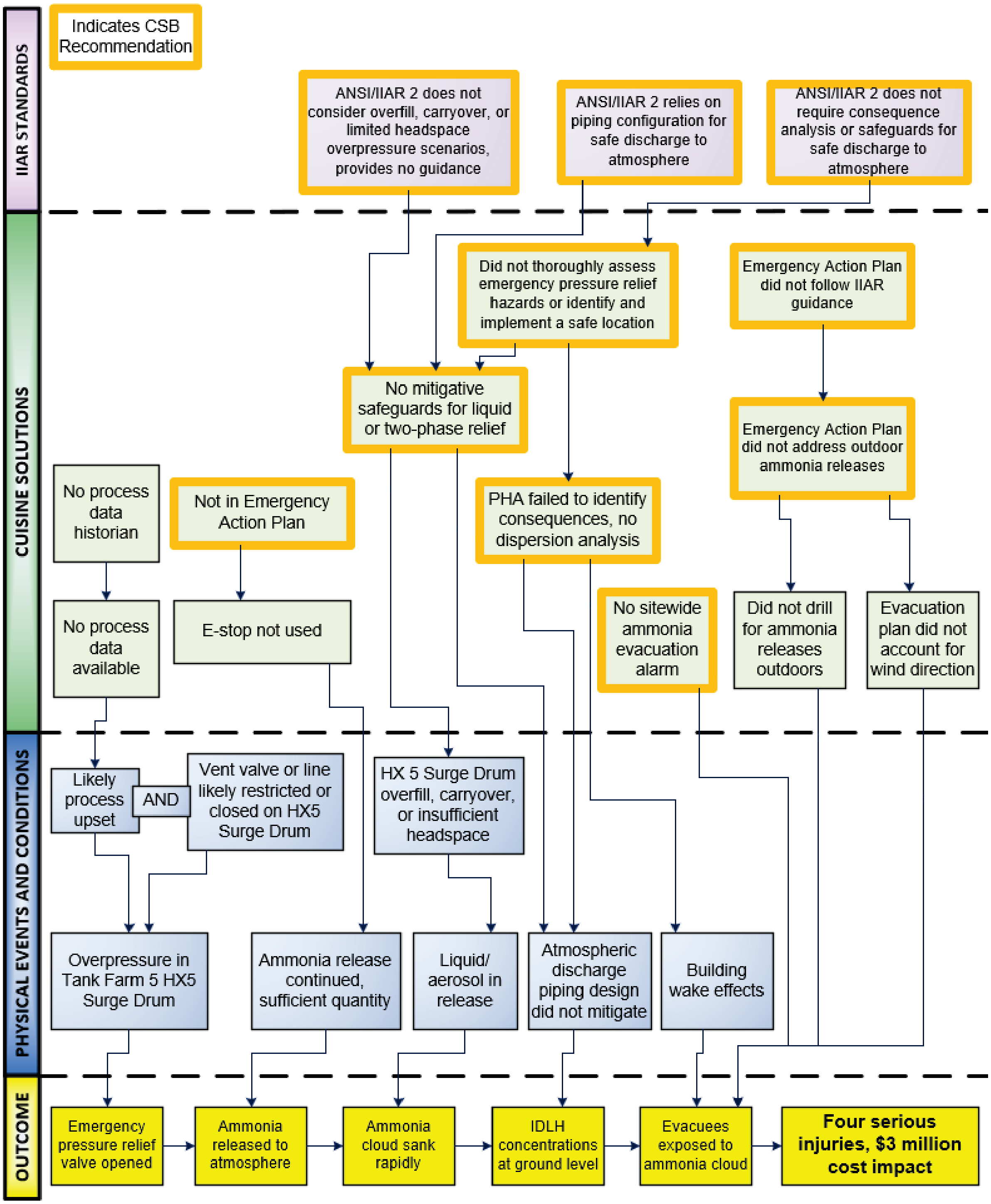
[52] American Society of Mechanical Engineers (ASME), "ASME Boiler and Pressure Vessel Code, Section VIII, Division 1," 2021.

[53] Cambridge University Press & Assessment, "The Cambridge Dictionary," [Online]. Available: https://dictionary.cambridge.org/us/dictionary/english/windsock. [Accessed 16 September 2025].

[54] International Institute of Ammonia Refrigeration (IIAR), "Ammonia Refrigeration Education and Training Program Basic Ammonia Refrigeration Module 6 - Shut-Off Valves," IIAR, Alexandria, Virginia, 2004.

[55] International Institute of Ammonia Refrigeration (IIAR), "ANSI/IIAR 2-2014, Standard for Safe Design of Closed-Circuit Ammonia Refrigeration Systems," IIAR, Alexandria, Virginia, 2014.

Appendix A—Simplified Causal Analysis (AcciMap)



APPENDIX B—DESCRIPTION OF SURROUNDING AREA

Figure B-1 below shows the 12 census tracts within approximately five miles of the Cuisine Solutions site in Sterling, Virginia that the CSB reviewed.

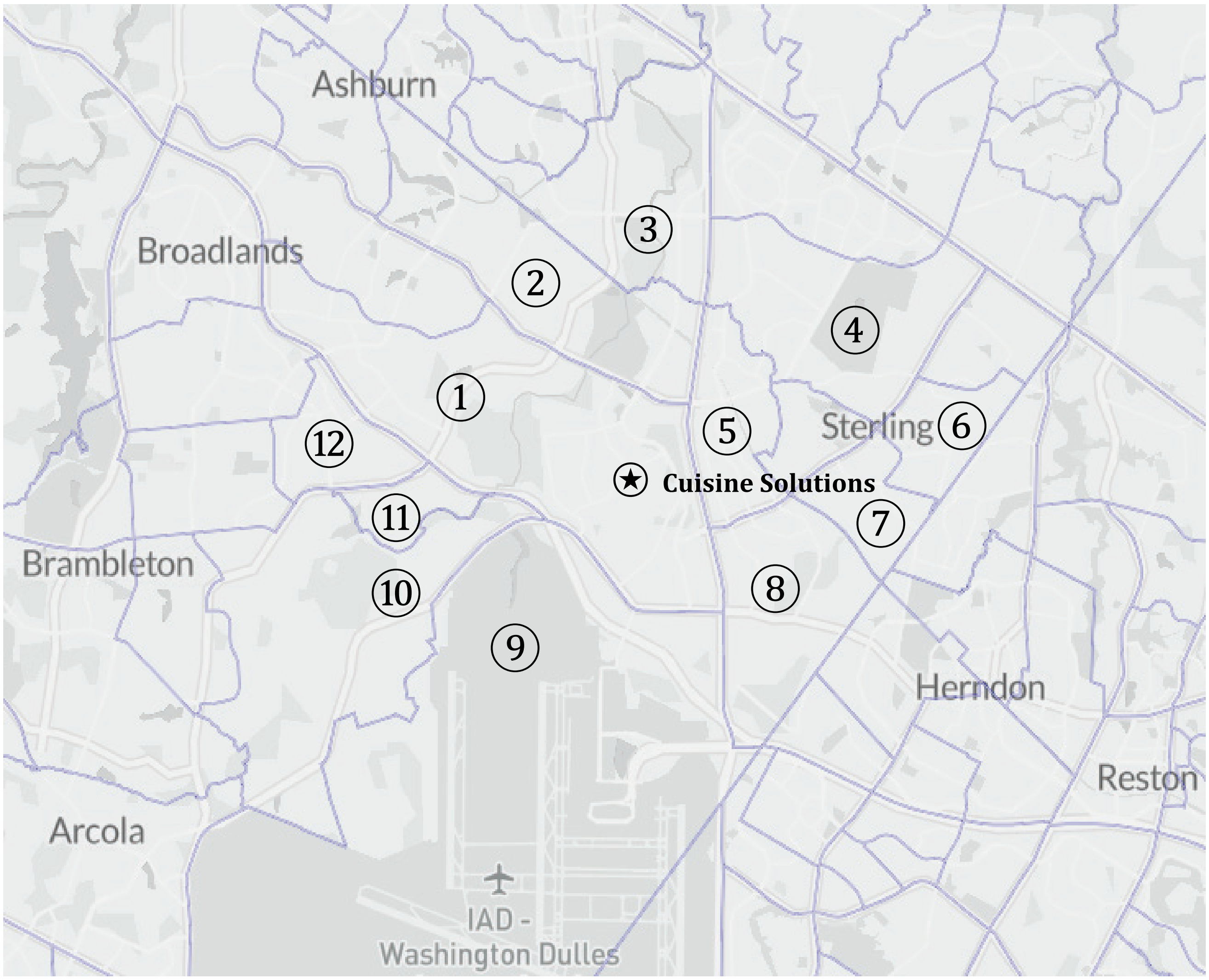


Figure B-1: Census tracts near the Sterling site. (Credit: Census Reporter, annotated by CSB)

Table B-1 contains the demographic data for each of the census tracts with a total population of 50,926.

Table B-1: Tabulation of demographic data.

Tract Number	Population	Median Age	Race and Ethnicity (%)		Per Capita Income ($)	Poverty (%)	Number of Housing Units	Types of Housing Units (%)	
1	7,144	34.3	38	White	59,405	2.7	2,865	57	Single Unit
			8	Black				43	Multi-Unit
			0	Native				0	Mobile Home
			33	Asian				0	Boat, RV, van, etc.
			0	Islander					
			2	Other					
			8	Two+					
			11	Hispanic					
2	5,577	37.6	54	White	68,356	1.3	1,779	91	Single Unit
			7	Black				9	Multi-Unit
			0	Native				0	Mobile Home
			22	Asian				0	Boat, RV, van, etc.
			0	Islander					
			0	Other					
			2	Two+					
			14	Hispanic					
3	3,794	74	69	White	59,049	7.0	2,211	17	Single Unit
			6	Black				83	Multi-Unit
			0	Native				0	Mobile Home
			12	Asian				0	Boat, RV, van, etc.
			0	Islander					
			0	Other					
			4	Two+					
			9	Hispanic					
4	6,998	40.3	28	White	45,831	5.3	2,099	87	Single Unit
			11	Black				13	Multi-Unit
			0	Native				0	Mobile Home
			17	Asian				0	Boat, RV, van, etc.
			0	Islander					
			0	Other					
			1	Two+					
			43	Hispanic					

Tract Number	Population	Median Age	Race and Ethnicity (%)		Per Capita Income ($)	Poverty (%)	Number of Housing Units	Types of Housing Units (%)	
5	4,035	35.4	41	White	57,552	2.9	1,498	85	Single Unit
			8	Black				13	Multi-Unit
			0	Native				2	Mobile Home
			14	Asian				0	Boat, RV, van, etc.
			0	Islander					
			2	Other					
			4	Two+					
			31	Hispanic					
6	4,000	35.4	14	White	30,460	9.9	1,351	60	Single Unit
			5	Black				40	Multi-Unit
			0	Native				0	Mobile Home
			21	Asian				0	Boat, RV, van, etc.
			0	Islander					
			1	Other					
			1	Two+					
			58	Hispanic					
7	4,705	42.3	45	White	52,191	5.7	1,705	80	Single Unit
			5	Black				19	Multi-Unit
			0	Native				0	Mobile Home
			6	Asian				1	Boat, RV, van, etc.
			0	Islander					
			1	Other					
			1	Two+					
			42	Hispanic					
8	2,533	33.1	34	White	53,380	2.3	764	94	Single Unit
			10	Black				6	Multi-Unit
			0	Native				0	Mobile Home
			39	Asian				0	Boat, RV, van, etc.
			0	Islander					
			0	Other					
			0	Two+					
			17	Hispanic					
9 Washington	0	-	-	White	-	-	0	-	Single Unit
			-	Black				-	Multi-Unit
			-	Native				-	Mobile Home

Tract Number	Population	Median Age	Race and Ethnicity (%)		Per Capita Income ($)	Poverty (%)	Number of Housing Units	Types of Housing Units (%)	
Dulles International Airport (IAD) ✈			-	Asian				-	Boat, RV, van, etc.
			-	Islander					
			-	Other					
			-	Two+					
			-	Hispanic					
10	6,859	39.0	30	White	79,163	3.7	2,267	97	Single Unit
			4	Black				3	Multi-Unit
			0	Native				0	Mobile Home
			52	Asian				0	Boat, RV, van, etc.
			0	Islander					
			1	Other					
			4	Two+					
			9	Hispanic					
11	2,961	32.3	34	White	42,082	11.4	996	45	Single Unit
			8	Black				55	Multi-Unit
			1	Native				0	Mobile Home
			39	Asian				0	Boat, RV, van, etc.
			0	Islander					
			2	Other					
			5	Two+					
			10	Hispanic					
12	2,320	36.8	52	White	84,944	0.0	896	97	Single Unit
			6	Black				3	Multi-Unit
			0	Native				0	Mobile Home
			19	Asian				0	Boat, RV, van, etc.
			0	Islander					
			0	Other					
			4	Two+					
			19	Hispanic					

APPENDIX C—EMERGENCY PRESSURE RELIEF VALVE TESTING

The CSB commissioned an independent VR Shop to test all emergency pressure relief valves in Tank Farm 5 that were a Cyrus Shank model 800QR, ½-inch by ¾-inch. Fifteen emergency pressure relief valves fit this description. One of these emergency pressure relief valves had been set aside as the one that opened on the night of the incident. This valve is highlighted below in yellow. **Table C-1** below shows the individual test runs and the average for each emergency pressure relief valve. Each device was tested three times. According to the IRC, among others, acceptable opening pressure is 90 to 100 percent of set pressure (270 to 300 psig in this case) [20, p. 15]. All devices demonstrated opening pressures in the acceptable range.

Table C-1: Opening pressures for each emergency pressure relief valve. The device believed to have opened during the incident is highlighted in yellow. (Credit: CSB)

Device #	Serial #	Test 1 (psig)	Test 2 (psig)	Test 3 (psig)	Average of 3 tests (psig)
1	2554	296	284	284	288.0
2	2658	293	290	292	291.7
3	2660	281	285	289	285.0
4	6277	294	295	294	294.3
5	2659	299	297	298	298.0
6	6275	291	272	287	283.3
7	6279	298	295	297	296.7
8	2661	289	292	294	291.7
9	6276	299	297	296	297.3
10	2657	290	290	284	288.0
11	2656	292	292	291	291.7
12	2653	293	295	299	295.7
13	2652	295	291	294	293.3
14	6280	293	290	290	291.0
15	6281	288	286	288	287.3

Emergency pressure relief valve testing included recording the pressure at which each device reseated, also known as "blowdown." The blowdown was also recorded for each test, as shown below in **Table C-2**. According to the manufacturer, the acceptable range for blowdown is 215-265 psig [21, p. 61]. All devices demonstrated blowdown in the acceptable range.

Table C-2: Blowdown pressures for each emergency pressure relief valve. The device believed to have opened during the incident is highlighted in yellow. (Credit: CSB)

Device #	Serial #	Test 1 (psig)	Test 2 (psig)	Test 3 (psig)	Average of 3 tests (psig)
1	2554	252	249	249	250.0
2	2658	253	252	252	252.3
3	2660	253	252	251	252.0
4	6277	245	245	246	245.3
5	2659	255	255	254	254.7
6	6275	249	248	248	248.3
7	6279	244	244	245	244.3
8	2661	242	244	245	243.7
9	6276	250	250	250	250.0
10	2657	249	250	250	249.7
11	2656	251	250	250	250.3
12	2653	254	255	255	254.7
13	2652	250	250	250	250.0
14	6280	243	242	242	242.3
15	6281	252	252	252	252.0

Finally, at the end of the final test for each device, the emergency pressure relief valves were "bubble-tested," that is, tested to determine whether any air leakage could be detected with 270 psig on the emergency pressure relief valve inlet. For this qualitative test, a soap bubble was placed across the device discharge. If the soap bubble popped, this was considered a "moderate leak." After these tests, three devices were disassembled for internal inspection. The results of these tests and examinations are shown in **Table C-3**. Four of the devices exhibited a moderate leak past the soap bubble, and one showed mild corrosion on internal parts.

Table C-3: Leak rate and teardown results for each emergency pressure relief valve. The device believed to have opened during the incident is highlighted in yellow. (Credit: CSB)

Device #	Serial #	Post-test 90% leak rate (at 270 psig)	Teardown results
1	2554	Moderate leak	No issues found
2	2658	Tight	Not disassembled
3	2660	Tight	Not disassembled
4	6277	Tight	Not disassembled
5	2659	Tight	Not disassembled
6	6275	Moderate leak	No issues found
7	6279	Moderate leak	Not disassembled
8	2661	Tight	Not disassembled
9	6276	Tight	Not disassembled
10	2657	Moderate leak	Mild corrosion on internal parts
11	2656	Tight	Not disassembled
12	2653	Tight	Not disassembled
13	2652	Tight	Not disassembled
14	6280	Tight	Not disassembled
15	6281	Tight	Not disassembled

Appendix D—Dispersion Analysis

See separate file for independent dispersion analysis commissioned by CSB.

U.S. Chemical Safety and Hazard Investigation Board

Members of the U.S. Chemical Safety and Hazard Investigation Board:

Steve Owens
Chairperson

Sylvia E. Johnson, Ph.D.
Member