

APPENDIX E:
Supplemental Risk Management Program Guidance for
Ammonia Refrigeration Facilities

Appendix E: Supplemental Risk Management Program Guidance for Ammonia Refrigeration Facilities

This appendix supplements the main body of the General Guidance to provide additional information for food processors, food distributors, and refrigerated warehouses who use ammonia as a refrigerant, as well as any other facility that has an ammonia refrigeration system. If you have other processes that use regulated substances other than ammonia, refer to the main body of the *General Guidance* (and any other applicable industry-specific appendix) for information on compliance with the rule for those processes. The appendix covers Risk Management Program elements in the same general order as those elements are addressed in the main document. However, note that the appendix does not address some generic RMP elements (e.g., Management System). For elements not addressed in this appendix, simply refer to the applicable guidance in the main document.

E.1 General Applicability

EXEMPTION FOR FARMS

The rule exempts ammonia when held by a farmer for use as an agricultural nutrient on a farm. This exemption does not apply to agricultural suppliers, fertilizer manufacturers, or the use of ammonia as a refrigerant. It does not apply to farm cooperatives or to groups of farmers who buy, use, and sell ammonia.

THRESHOLD QUANTITY

The threshold quantity for anhydrous ammonia is 10,000 pounds.

CO-LOCATION OF PROCESS VESSELS

For ammonia, a release from a single vessel will not normally lead to a release from others unless the vessel fails catastrophically and explodes, sending metal fragments into other vessels. Co-located vessels containing ammonia, however, may well be involved in a release caused by a fire or explosion that occurs from another source.

E.2 Applicability of Program Levels

QUICK RULES FOR DETERMINING PROGRAM 1 ELIGIBILITY

If you have a process containing more than a threshold quantity of ammonia that is not liquefied by refrigeration alone (i.e., you hold it as a gas or liquefied under pressure), the distance to the endpoint estimated for a worst-case release may be several miles. As a result, the distance to endpoint is unlikely to be less than the distance to public receptors, unless the process is very remote. In some cases,

however, ammonia in processes contained in enclosed areas may be eligible for Program 1.

If you have a process containing anhydrous ammonia liquefied by refrigeration alone, and your worst-case release would take place into a diked area, the chances are good that the process may be eligible for Program 1, unless there are public receptors very close to the process. Even if you have many times the threshold quantity of ammonia, the process may still be eligible for Program 1.

PROGRAM 3

Most ammonia refrigeration processes that are not eligible for Program 1 will be subject to Program 3 requirements because they are subject to the OSHA PSM Standard.

PROGRAM 2

Ammonia refrigeration processes will usually not be eligible for this program level because they are covered by OSHA PSM. If your ammonia process is not eligible for Program 1, it will generally be subject to Program 3. If your ammonia refrigeration process is subject to Program 2 requirements, this appendix does not contain additional information on prevention program elements; consult chapter 6 in the main document.

E.3 Offsite Consequence Analysis

This section gives simple guidance on how to perform the hazard assessment for anhydrous ammonia in ammonia refrigeration facilities. Additional technical information is provided in a separate document entitled “Technical Background Document for Offsite Consequence Analysis for Anhydrous Ammonia, Aqueous Ammonia, Chlorine and Sulfur Dioxide,” henceforth known as the “Technical Background Document”. This document is available from EPA’s website at www.epa.gov/emergencies.

E.3.1 Worst-Case Release Scenario Analysis

MANDATORY INPUTS

The following inputs are required by the Risk Management Program rule:

Release Quantity: The worst-case release quantity (lb) shall be the greater of the following:

- For substances in a vessel, the greatest amount held in a vessel, taking into account administrative controls that limit the maximum quantity; or

- For substances in pipes, the greatest amount in a pipe, taking into account administrative controls that limit the maximum quantity.

Section E.3.3 shows that, for ammonia refrigeration systems, a storage vessel or receiver is the place where the worst-case release quantity is expected to reside.

Per §68.25(c)(1), because ammonia is a vapor at ambient temperature and is handled as a liquid under pressure in most parts of a refrigeration system, the release quantity is assumed to be completely released from the vessel over a period of 10 minutes. This applies whether the release takes place outside or in a building.

Wind speed/atmospheric stability class: The owner or operator shall use a wind speed of 1.5 meters per second and F stability class. If the owner or operator can demonstrate that local meteorological data show a higher minimum wind speed or a less stable atmosphere at all times during the previous three years, these site-specific conditions may be used. For simplicity's sake, the guidance presented below is restricted to a wind speed of 1.5 meters per second and F stability class.

Toxic Endpoint: The toxic endpoint for ammonia is 200 ppm (0.14 mg/L). This airborne concentration has been published by the American Industrial Hygiene Association (AIHA) and is 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. The rule requires you to assume that the toxic endpoint is constant, even though the duration of release is only 10 minutes.

QUANTITY RELEASED AND RELEASE RATE IN THE WORST-CASE RELEASE SCENARIO

Quantity Released: Take the largest quantity (lb) of ammonia that is liquefied under pressure in any vessel in the ammonia refrigeration system. For many systems, this vessel will be the high pressure receiver with typical pressures in the range 100 to 200 psig. Other candidate vessels include: a) an outside vessel in which ammonia is stored as a liquid at ambient temperature (some, but not all, facilities have such a vessel); b) an intermediate receiver with typical pressures in the range 20 to 60 psig (typical of two-stage ammonia refrigeration systems); or c) a low-pressure receiver with pressures in the range 10-60 psig (typical of single-stage refrigeration systems).

In the case of a vessel, the quantity *does not* include any liquid ammonia in pipework connected to the vessel and in any other vessel that can discharge directly into pipework connected to the vessel. In addition, the maximum amount of ammonia that could be in the vessel at any one time, not just during normal operation, should be considered. For example, if the vessel is used to store some or all of the ammonia while the rest of the system is being serviced, then the quantity released should include the additional quantity of ammonia that is in the vessel at such a time. However, if there are administrative controls that limit the amount of ammonia that is allowed in the vessel at any one time, this limit can also be taken into account when

estimating the quantity released. Similarly, if the largest quantity resides in a pipeline, you do not need to consider the quantity of ammonia in connected vessels.

Release Rate - Unmitigated Releases: For the worst-case scenario for a substance that is a gas under ambient conditions, the largest vessel is assumed to fail in a catastrophic manner, and the release occurs over a period of 10 minutes. The worst-case release rate is:

$$QR = Q/10 \quad (1)$$

where: QR = Release rate (lbs/min)

Q = Quantity released (lbs)

The rapid release of ammonia initially liquefied under pressure leads to an airborne mixture of vapor and droplets. If the vessel is outdoors, all of the vapor and droplets remain airborne, and the release rate (QR) is the total inventory uniformly distributed over 10 minutes, as required by the rule.

Release Rate - Mitigated Releases: The rule allows you to consider passive mitigation in estimating the worst-case release rate. Figure E-1 displays the procedure to be followed to determine the release rate for the worst-case scenario. If the release takes place in a building, the building can be considered to provide passive mitigation, unless:

- The building may fail as a result of the release. This is unlikely except in the case of a large vessel in a very small room. As a rough rule of thumb, if the room volume (V) divided by the quantity of ammonia (Q) in the vessel is less than $0.1 \text{ ft}^3/\text{lb}$, you should look at the possibility that the release of ammonia will cause failures such as windows blowing out or doors blowing open.
- The release takes place facing an opening in the building (door or window). In this case, you should assume that the door or window will be open, and the ammonia will be released through these openings.

If the building may fail as a result of the release, estimate the release rate as for an unmitigated release (Equation 1, $QR = Q/10 \text{ lb/min}$). Similarly, if the release would take place facing doors or windows, the release rate is again the entire inventory uniformly distributed over 10 minutes (Equation 1).

If the above conditions do not apply, you can assume that rain-out of liquid droplets is facilitated by impingement on surfaces (in a compressor room, for example), and only a portion of the released material will become airborne. The remainder collects in relatively slowly evaporating pools and makes only a small contribution to the rate of release from the building. To estimate the mitigated release rate, assume the following:

- The amount of material airborne in the building is four-tenths of the total inventory, or 0.4 Q.
- The airborne material includes 0.2 Q vapor and 0.2 Q liquid droplets.
- Exhibit E-1 provides factors for estimating the mitigated release rate from a building.

To estimate the release rate using these factors, do the following:

- Estimate **1** as follows:
 - Determine room volume, V, in ft³
 - Calculate **1** from room volume divided by the quantity of ammonia initially released as vapor, or $\mathbf{1}(\text{ft}^3/\text{lb}) = V/(0.2 Q)$
- Determine the active ventilation rate, N_v, in room volumes exchanged per hour (hr⁻¹), for the building.
- From Exhibit E-1, find the 10-minute building attenuation factor, FR₁₀, corresponding to your estimated **1** and the ventilation rate, N_v.
- Estimate the release rate in lbs/min from the building attenuation factor and the airborne quantity (0.4 Q) as follows, assuming the release takes place over 10 minutes:

$$QR_B = (FR_{10} \times 0.4Q)/10 \quad (2)$$

Example 1

A high-pressure receiver containing 5,000 lb of ammonia is in a room of dimensions 20 feet x 50 feet x 30 feet = 30,000 ft³. Hence, $\mathbf{1} = 30,000/(5,000 \times 0.2) = 30 \text{ ft}^3/\text{lb}$. The nearest value of **1** on Exhibit E-1 is $\mathbf{1} = 25$. The ventilation rate for the building is 5 hr⁻¹. For $\mathbf{1} = 25$ and N_v = 5, FR₁₀ = 0.35, and the release rate to the atmosphere is $QR_B = (0.35)(0.4)(5,000)/10 = 70 \text{ lb/min}$, using Equation 2 above.

Figure E-1
Guidance on Effectiveness of Building Mitigation for Worst-Case Scenarios

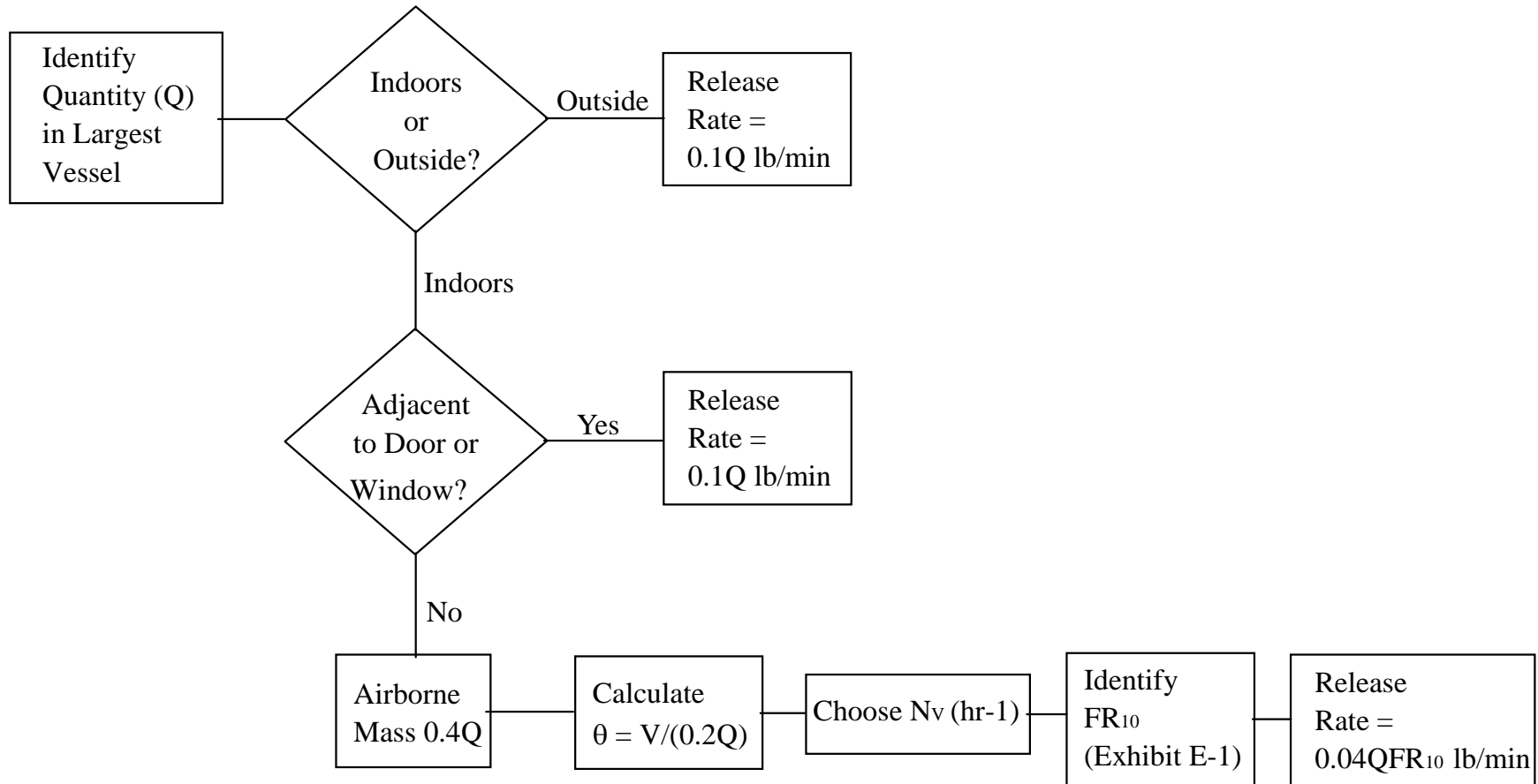


Exhibit E-1
Ten-Minute Building Release Attenuation Factors for Prolonged Releases

1	N_v	FR₁₀		1	N_v	FR₁₀
(ft³/lb)	(hr⁻¹)	(dim)		(ft³/lb)	(hr⁻¹)	(dim)
150.0	0	0.07		10.0	0	0.61
	1	0.08			1	0.61
	5	0.32			5	0.61
	10	0.51			10	0.61
	20	0.71			20	0.71
	30	0.80			30	0.80
	40	0.85			40	0.85
100.0	0	0.11		5.0	0	0.79
	1	0.11			1	0.79
	5	0.32			5	0.79
	10	0.51			10	0.79
	20	0.71			20	0.79
	30	0.80			30	0.80
	40	0.85			40	0.85
50.0	0	0.20		1.0	0	0.96
	1	0.20			1	0.96
	5	0.32			5	0.96
	10	0.51			10	0.96
	20	0.71			20	0.96
	30	0.80			30	0.96
	40	0.85			40	0.96
25.0	0	0.35		0.5	0	0.98
	1	0.35			1	0.98
	5	0.35			5	0.98
	10	0.51			10	0.98
	20	0.71			20	0.98
	30	0.80			30	0.98
	40	0.85			40	0.98

Example 2

The 5,000 lb vessel in Example 1 is outside. The release rate is, therefore, $5,000/10 = 500$ lb/min. It can be seen that the building provides extensive attenuation. However, to take advantage of this potential attenuation, you must be certain that the worst-case scenario cannot occur outside or adjacent to a door or window that may be open.

OTHER POTENTIAL WORST-CASE SCENARIOS

The rule requires that you look for other potential scenarios that could affect offsite populations further away from the site or in different areas than does the release from the largest vessel. Thus, even if an outside storage vessel is smaller than your high-pressure receiver, you should consider the release of its contents over a 10-minute period as a possible worst-case scenario. Similarly, if a pipe containing ammonia liquefied under pressure is outside for part of its length, you should consider the release of the contents of that pipe as a possible worst-case scenario.

DISTANCE TO THE TOXIC ENDPOINT

Take the estimated worst-case rate of release QR (unmitigated) or QR_B (in a building) and go to Exhibit E-2. Find the entry in the "Rate of Release" column that is closest to your estimated release rate. Read off the corresponding distance from the urban or the rural column. This is the "distance to the endpoint" that must be submitted (in miles) in the RMP information.

To decide whether the site is rural or urban, the rule gives the following guidance in § 68.22(e): "Urban means that there are many obstacles in the immediate area; obstacles include buildings or trees. Rural means that there are no buildings in the immediate area and the terrain is generally flat and unobstructed."

Figure E-2 represents Exhibit E-2 in graphical form. Both apply to releases of 10 minutes duration.

Example 3

Take the 500 lb/min release rate from Example 2. From Exhibit E-2, the predicted distance to the toxic endpoint is ~ 1.3 miles at a rural site and ~ 0.9 miles at an urban site. For the 70 lb/min release of Example 1, these distances become 0.5 miles and 0.3 miles, respectively.

Exhibit E-2
Distances to Toxic Endpoint for Anhydrous Ammonia Liquefied Under Pressure
F Stability, Wind Speed 1.5 Meters per Second

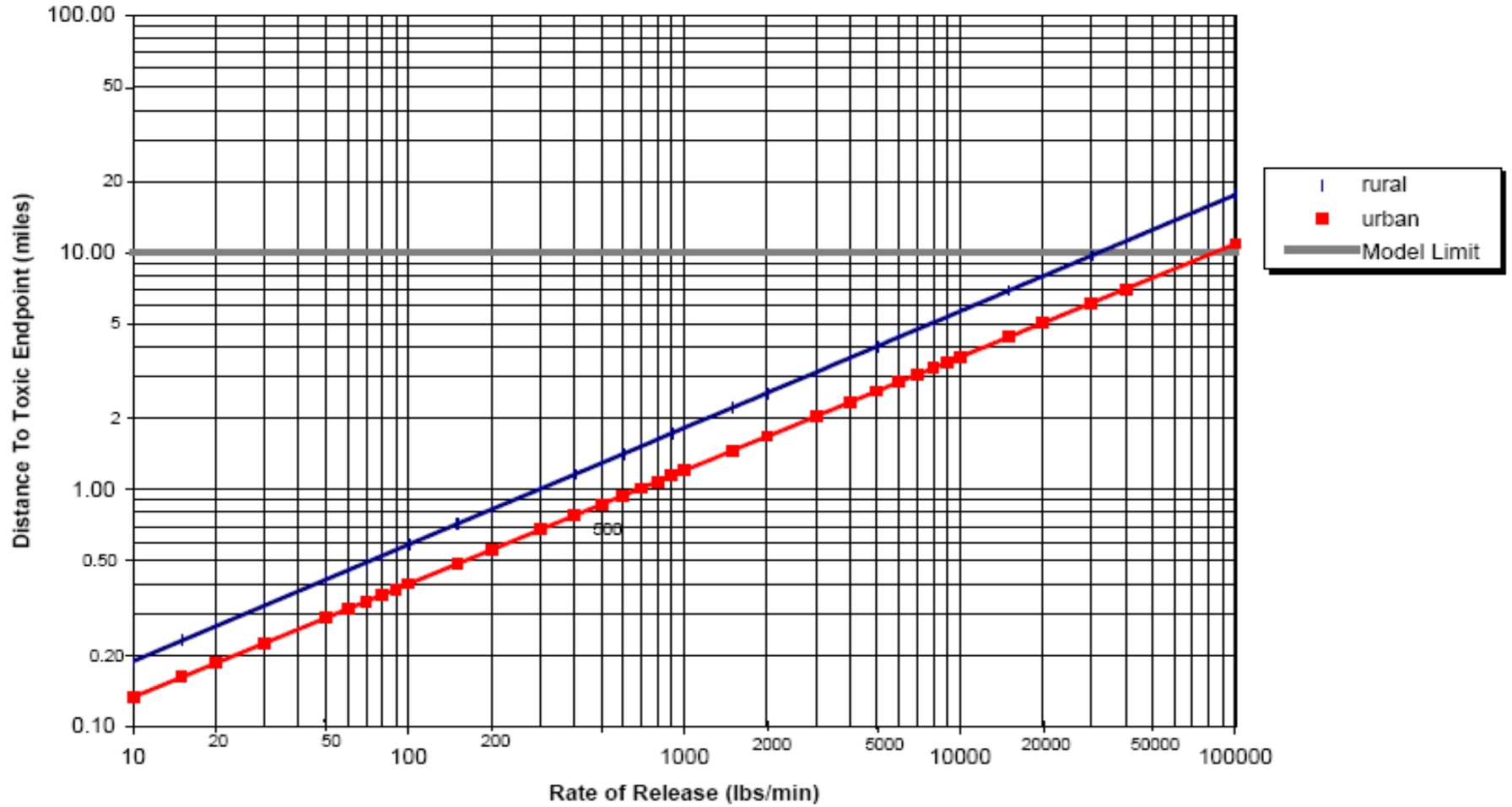
Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1	0.1	<0.1*
2	0.1	0.1
5	0.1	0.1
10	0.2	0.1
15	0.2	0.2
20	0.3	0.2
30	0.3	0.2
40	0.4	0.3
50	0.4	0.3
60	0.5	0.3
70	0.5	0.3
80	0.5	0.4
90	0.6	0.4
100	0.6	0.4
150	0.7	0.5
200	0.8	0.6
250	0.9	0.6
300	1.0	0.7
400	1.2	0.8
500	1.3	0.9
600	1.4	0.9
700	1.5	1.0
750	1.6	1.0
800	1.6	1.1
900	1.7	1.2

*Report distance as 0.1 mile

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1,000	1.8	1.2
1,500	2.2	1.5
2,000	2.6	1.7
2,500	2.9	1.9
3,000	3.1	2.0
4,000	3.6	2.3
5,000	4.0	2.6
6,000	4.4	2.8
7,000	4.7	3.1
7,500	4.9	3.2
8,000	5.1	3.3
9,000	5.4	3.4
10,000	5.6	3.6
15,000	6.9	4.4
20,000	8.0	5.0
25,000	8.9	5.6
30,000	9.7	6.1
40,000	11	7.0
50,000	12	7.8
75,000	15	9.5
100,000	18	10
150,000	22	13
200,000	**	15
250,000	**	17
750,000	**	**

** More than 25 miles (report distance as 25 miles)

Figure E-2
Worst-Case Scenario - Predicted Distances to Toxic Endpoint
Anhydrous Ammonia @ Atmospheric Stability Class F with Wind speed 1.5 m/s



E.3.2 Alternative Release Scenario Analysis

The owner or operator must identify and analyze at least one “alternative” release scenario.

CHOICE OF THE ALTERNATIVE SCENARIO

Your alternative scenario for a covered process must be one that is more likely to occur than the worst-case scenario and that reaches an endpoint offsite, unless no such scenario exists. Note that this requirement means that the release rate for the alternative scenario for ammonia must be fairly large, or it generally will not reach the ammonia endpoint offsite.

ALTERNATIVE SCENARIOS FOR AMMONIA AT REFRIGERATION FACILITIES

For the alternative scenario analysis, you need to estimate the release rate of ammonia and the distance to the toxic endpoint. Exhibit E-3 and Figure E-3 provide distances to the endpoint for a range of release rates under the weather conditions discussed above. Note that Exhibit E-3 and Figure E-3 (and Equations 6 and 7 in Section E.3.4) are intended to apply to releases of any duration.

For the purposes of this guidance, a simple alternative scenario has been chosen: an outdoor release through a hole in a tank or pipe containing ammonia liquefied under pressure, leading to an airborne release. For the release of liquid, you can estimate the release rate from the Bernoulli Equation; for ammonia liquefied under pressure, you can assume the liquid vaporizes immediately, and the release rate of the liquid is the same as the release rate to air. The following is a simplified version of the Bernoulli Equation, incorporating chemical-specific factors for ammonia:

$$QR = HA \times (203)(Pg)^{1/2} \quad (3)$$

where: QR = Release rate (pounds per minute)

HA = Hole area (square inches)

Pg = Gauge pressure (psig)

See Section E.3.4 for a discussion of the Bernoulli Equation and the derivation of the simplified equation above.

Exhibit E-3
Distances to Toxic Endpoint for Anhydrous Ammonia Liquefied Under Pressure
D Stability, Wind Speed 3 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
<10	<0.1*	<0.1*
10	0.1	
15	0.1	
20	0.1	
30	0.1	
40	0.1	
50	0.1	
60	0.2	
70	0.2	0.1
80	0.2	0.1
90	0.2	0.1
100	0.2	0.1
150	0.2	0.1
200	0.3	0.1
250	0.3	0.1
300	0.3	0.1
400	0.4	0.2
500	0.4	0.2
600	0.5	0.2
700	0.5	0.2
750	0.5	0.2
800	0.5	0.2

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
900	0.6	0.2
1,000	0.6	0.2
1,500	0.7	0.3
2,000	0.8	0.3
2,500	0.9	0.3
3,000	1.0	0.4
4,000	1.2	0.4
5,000	1.3	0.5
7,500	1.6	0.5
10,000	1.8	0.6
15,000	2.2	0.7
20,000	2.5	0.8
25,000	2.8	0.9
30,000	3.1	1.0
40,000	3.5	1.1
50,000	3.9	1.2
75,000	4.8	1.4
100,000	5.4	1.6
150,000	6.6	1.9
200,000	7.6	2.1
250,000	8.4	2.3
300,000	9.2	2.5

* Report distance as 0.1 mile

Figure E-3
Alternative Release Scenario - Estimated Distances to Toxic Endpoint for Anhydrous Ammonia
Stability Class D, Wind Speed 3 Meters per Second

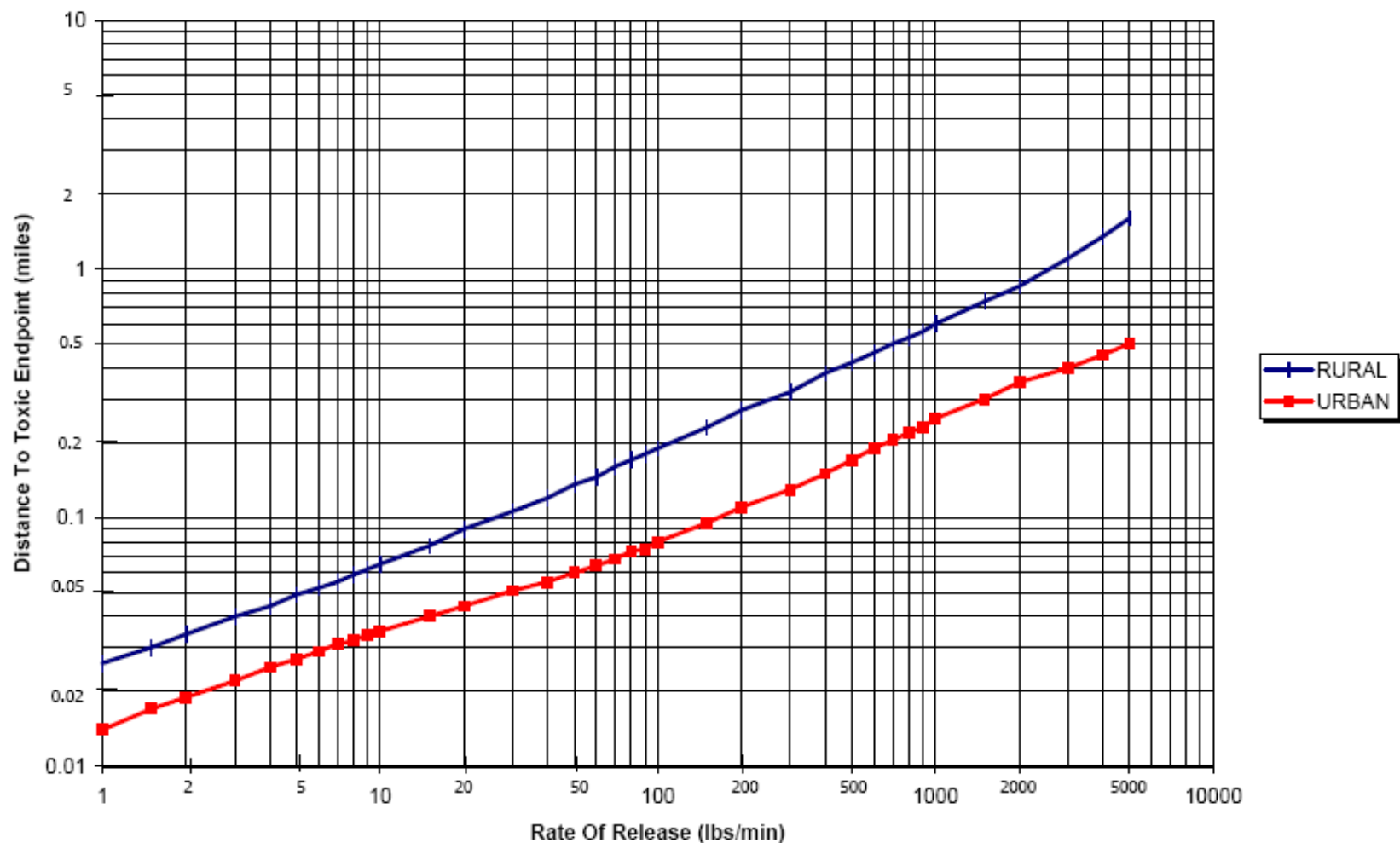


Exhibit E-4 provides release rates and distances for pressures of 100 to 180 psig and hole diameters of 1/4 inch to 12 inches. (The distances are based on Exhibit E-3). You may use this exhibit to estimate the distance to the endpoint if this type of scenario is reasonable for your site.

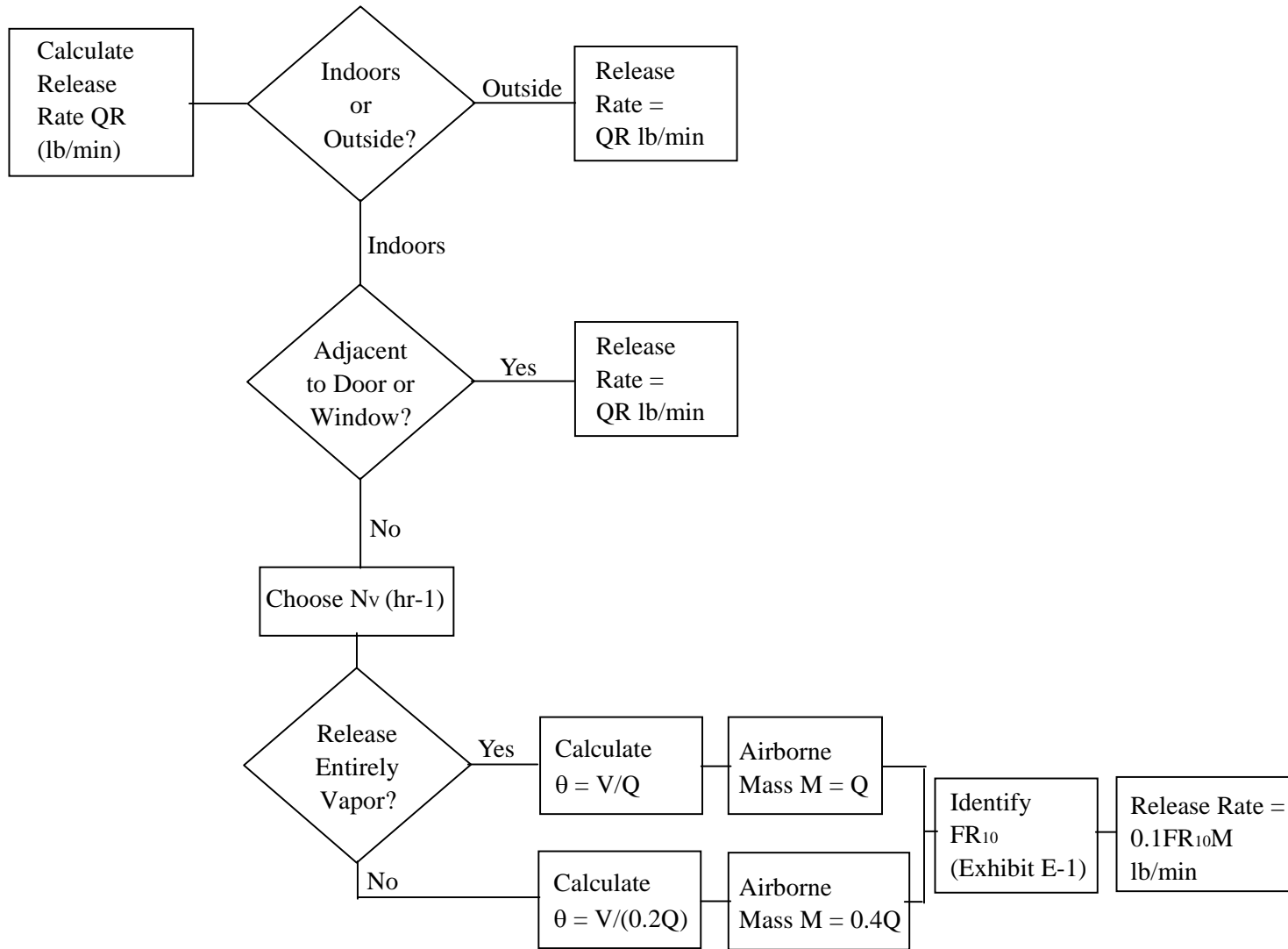
Exhibit E-4
Release Rates and Distances to Toxic Endpoint for Leaks of Anhydrous Ammonia
(Alternative Release Scenario)

Hole Diameter (inches)	Tank Pressure 100 psig			Tank Pressure 130 psig			Tank Pressure 180 psig		
	Release Rate (lb/min)	Distance (miles)		Release Rate (lb/min)	Distance (miles)		Release Rate (lb/min)	Distance (miles)	
		Rural	Urban		Rural	Urban		Rural	Urban
0.25	100	0.2	0.1	110	0.2	0.1	130	0.2	0.1
0.5	400	0.4	0.2	450	0.4	0.2	540	0.4	0.2
1	1,600	0.7	0.3	1,800	0.8	0.3	2,100	0.8	0.3
2	6,400	1.6	0.5	7,300	1.6	0.5	8,600	1.6	0.5
3	14,300	2.2	0.7	16,400	2.2	0.7	19,300	2.5	0.8
4	25,500	2.8	0.9	29,100	3.1	1.0	34,200	3.1	1.0
5	39,900	3.5	1.1	45,400	3.9	1.2	53,500	3.9	1.2
6	57,400	3.9	1.2	65,400	4.8	1.4	77,000	4.8	1.4
7	78,100	4.8	1.4	89,100	5.4	1.6	105,000	5.4	1.6
8	102,000	5.4	1.6	116,000	5.4	1.6	137,000	6.6	1.9
9	129,000	6.6	1.9	147,000	6.6	1.9	173,000	6.6	1.9
10	159,000	6.6	1.9	182,000	7.6	2.1	214,000	7.6	2.1
11	193,000	7.6	2.1	220,000	7.6	2.1	259,000	8.4	2.3
12	230,000	8.4	2.3	262,000	8.4	2.3	308,000	9.2	2.5

ALTERNATIVE RELEASE SCENARIOS INSIDE A BUILDING

The alternative release scenario inside a building is handled in much the same way as is the worst-case scenario. See Figure E-4 for a flow chart describing the procedure. To use the factors provided in Exhibit E-1 for estimating the release rate in a building, you must assume the release takes place over a ten-minute period. The total quantity released will be your estimated release rate multiplied by 10. If a ten minute release is not a reasonable alternative scenario for your site, you will need to do additional calculations or use a different method for releases in buildings.

Figure E-4
Guidance on Effectiveness of Building Mitigation for Alternative Release Scenarios



Example 4

Suppose the release from a ½-inch hole in a tank with pressure 180 psig, cited in Exhibit E-4, resulting in a release rate of 550 lb/min of flashing liquid ammonia, takes place inside a building with a ventilation rate $N_v = 5 \text{ hr}^{-1}$. The release is assumed to take place over ten minutes, and the total quantity released is $550 \times 10 = 5,500 \text{ lb}$, of which $0.4 \times 5,500 = 2,200 \text{ lb}$ becomes airborne. Of the airborne quantity, 1,100 lb is vapor and 1,100 lb is liquid that remains entrained in the vapor. The remaining 3,300 lb of liquid forms an evaporating pool on the floor. The building volume is 50 feet x 20 feet x 20 feet = 20,000 ft³, so that $\mathbf{1} = 20,000/1,100 = 18 \text{ ft}^3/\text{lb}$.

From Exhibit E-1, $FR_{10} = 0.35$ for $\mathbf{1} = 25 \text{ ft}^3/\text{lb}$ (the number closest to 18) and $N_v = 5$. Assuming a ten-minute release, the rate of release from the building is 77 lb/min [$QR_B = (0.35)(0.4)(5,500)/10$ from Equation 2 in section E.3.1]. Using Exhibit E-3, the predicted distance to the toxic endpoint is 0.2 mile for a rural site and 0.1 mile for an urban site, compared to 0.4 mile (rural) and 0.2 mile (urban) for the same release outdoors.

As noted above, the attenuation factors in Exhibit E-1 apply to ten-minute releases. If you want to use the same method to perform a calculation for a different duration of release in a building, consult the Technical Background Document cited at the beginning of this appendix for additional information on how to carry out such calculations.

E.3.3 Brief Summary of the Various States in Which Ammonia Exists in a Typical Refrigeration Facility

A typical block diagram of a two-stage ammonia refrigeration facility is shown on the next page; a similar diagram of a single-stage facility is shown on the following page.

AMMONIA LIQUEFIED UNDER PRESSURE

In many parts of a typical refrigeration system, there is ammonia liquefied under pressure. If the pressure and temperature are sufficiently high, and if there is a sudden release of liquid ammonia, it will all become and remain airborne as a mixture of ammonia vapor and very fine liquid droplets that do not fall to the ground, provided that no obstacles are encountered in the immediate vicinity of the release. Experimental results clearly show that this is a real physical phenomenon (Goldwire et al., 1985; Kaiser, 1989). The droplets evaporate quickly as air is entrained. The evaporation process cools the air so that a cold mixture of air and ammonia vapor is formed. The mixture is denser than air, and a heavy vapor dispersion model is required to adequately predict airborne concentrations downwind of the point of release.

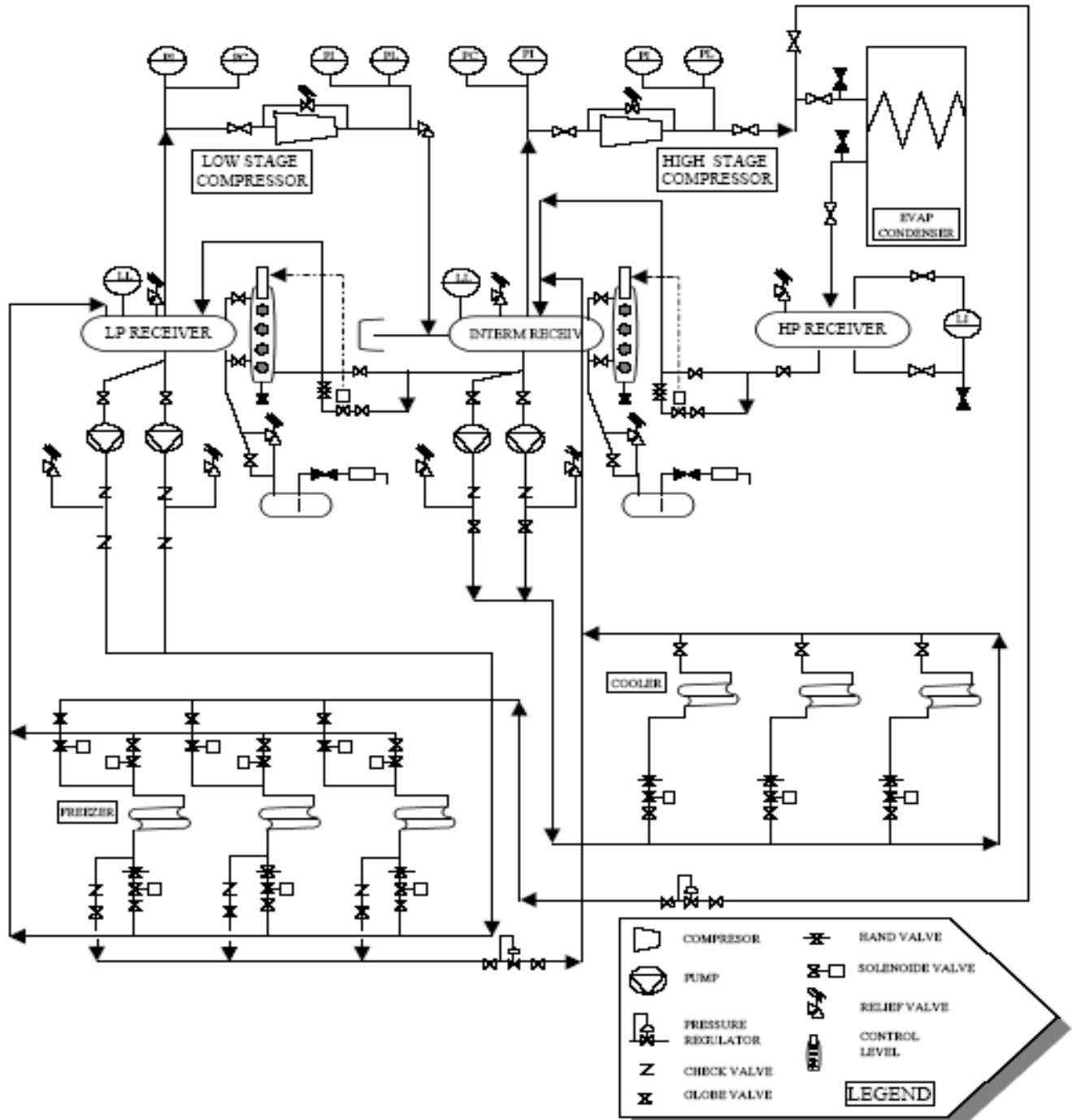
In many refrigeration facilities, the ammonia travels from the discharge of the compressors through the evaporative condensers to the high-pressure receiver. The next page shows a range of typical pressures in the high-pressure receiver from 100-200 psig (approximately 8-15 atmospheres). The figure shows ammonia vapor pressure as a function of temperature. Pressures of 8-15 atmospheres correspond to ammonia temperatures of approximately 10-40 degrees C, or superheats (number of degrees above the atmospheric boiling point) of about 40-70 degrees C. These conditions are definitely such as to ensure that all of any liquid ammonia release will become and remain airborne.

Some (but by no means all) refrigeration facilities have an ammonia storage vessel in addition to the high-pressure receiver. This vessel will, in all likelihood, be outside, and its pressure will fluctuate with the external temperature. However, at an ambient temperature of 25 degrees C, the superheat would be about 60 degrees C so that the characteristics of any release from such a vessel are expected to be similar to those of a release from the high-pressure receiver. A release from such a vessel should be considered as a candidate for the worst case.

Some refrigeration facilities may not have a high-pressure receiver. In such facilities, ammonia at pressures as high as 180 psig is confined to pipework, and there may be a low-pressure receiver with a typical pressure in the range 10-60 psig (~ 2-5 atmospheres), also containing ammonia liquefied under pressure. From Figure E-5, the corresponding temperatures are -20-0 degrees C, or superheats of 10-30 degrees C. It is only slightly conservative to assume that all of the ammonia released from such a vessel becomes airborne. Two-stage systems have an intermediate receiver,

which has a range of operating pressures similar to those for low-pressure receivers in a single-stage system.

Exhibit E-5 Two-Stage Ammonia Refrigeration System



**Exhibit E-6
Single-Stage Ammonia Refrigeration System with
High-Side Float Regulator and Pump Circulation**

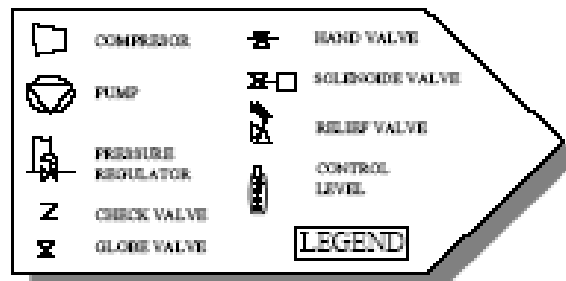
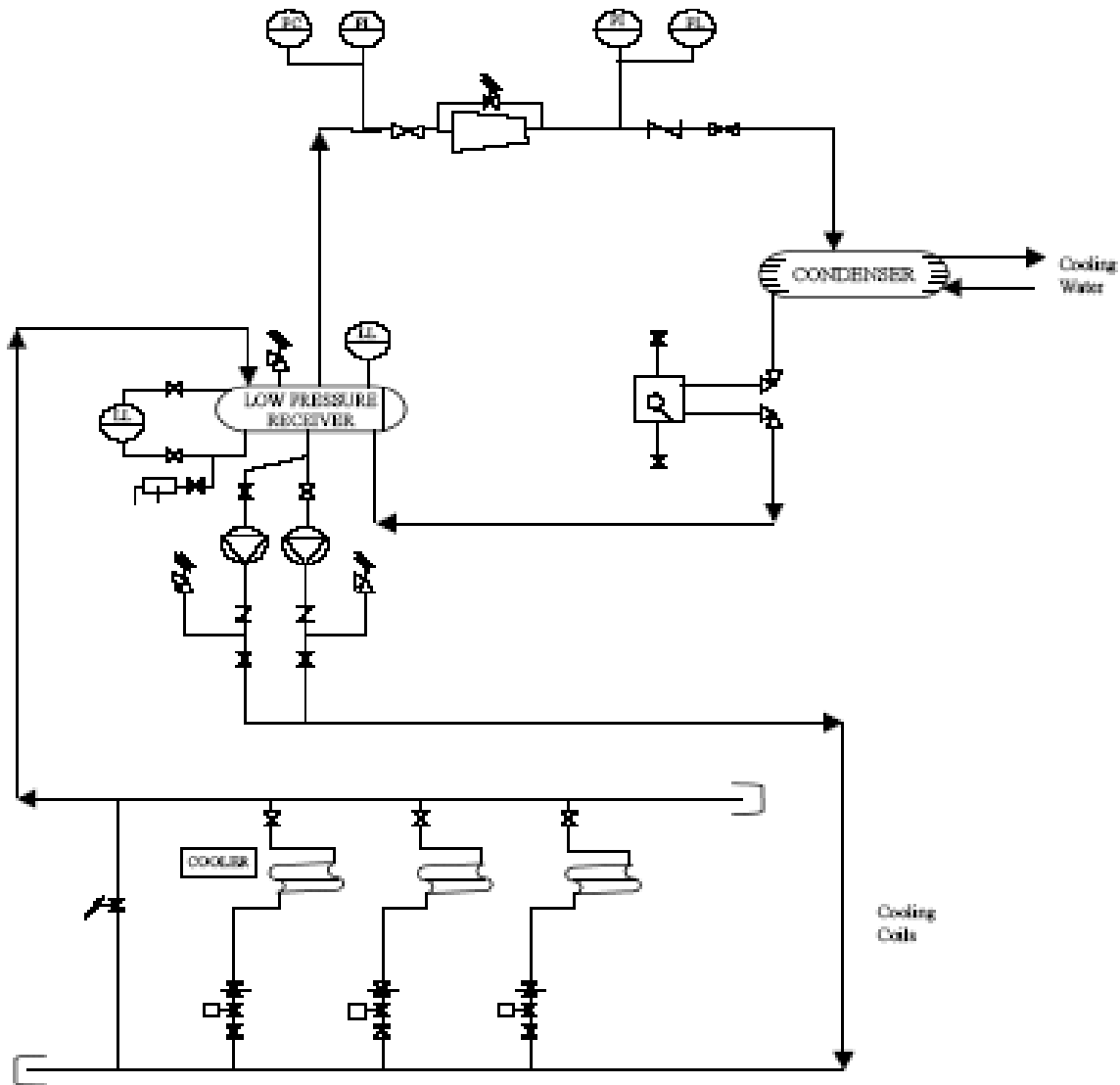
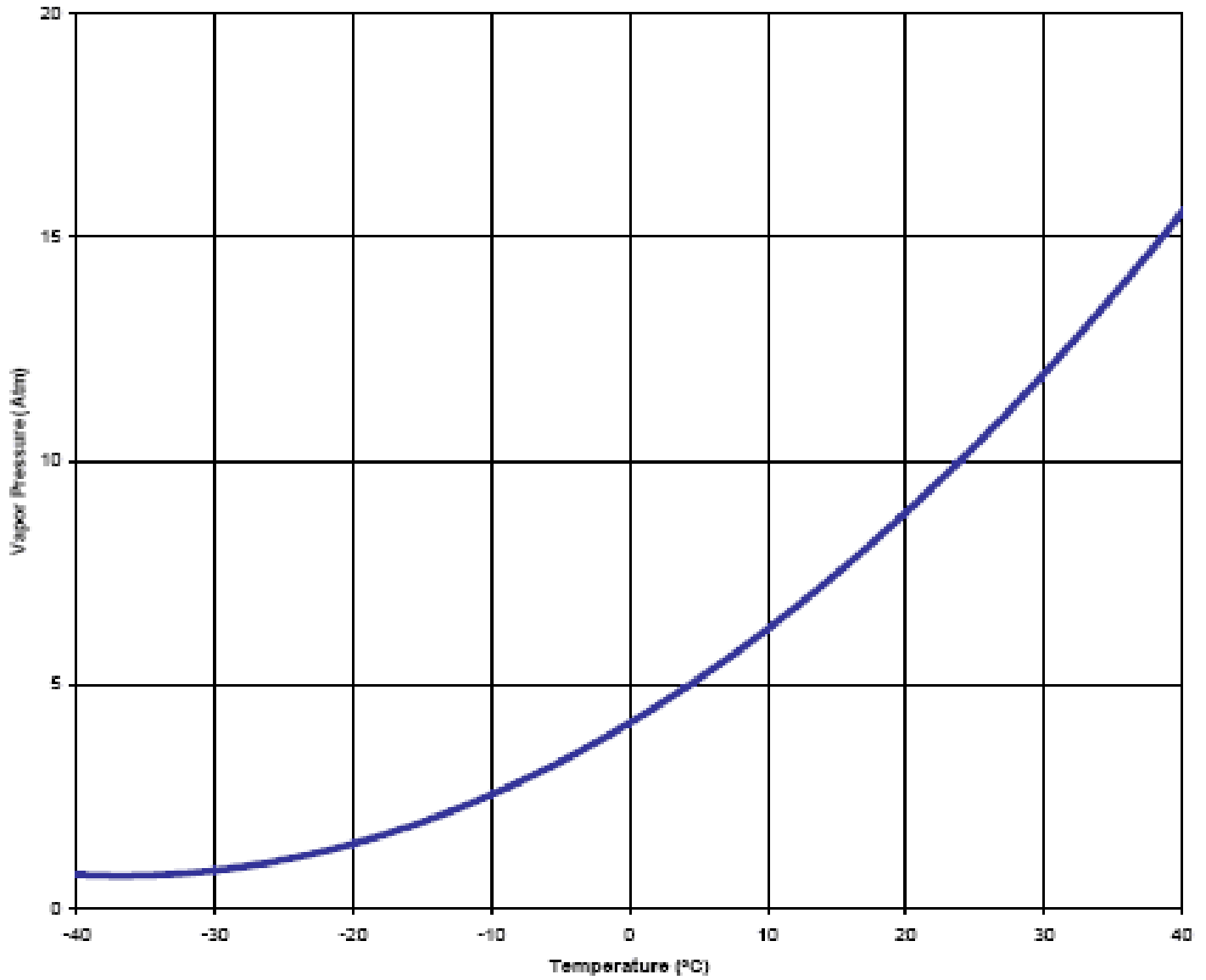


Figure E-5. Vapor Pressure of Ammonia as a Function of Temperature

AMMONIA AT SUBATMOSPHERIC PRESSURES

In some facilities (e.g., food processing plants), even colder ammonia may be needed (when, for example, very rapid freezing of food is necessary). The first figure shows a low-pressure receiver with subatmospheric pressures as low as 15 inches of water, which corresponds to a temperature well below the atmospheric boiling point. If released, the ammonia will spill onto the ground and, over an average period of 10 minutes or more, will evaporate at a much lower rate than a release from a worst-case rupture in such a vessel as the high-pressure receiver. In addition, these low temperature vessels are generally inside buildings, and it is likely that this would further reduce the effective rate of release to the atmosphere external to the refrigeration plant.

AMMONIA GAS

Finally, in ammonia refrigeration systems there is ammonia gas (vapor) in the system under a range of temperatures and pressures. If there is a rupture in the vapor space of the high-pressure receiver, there will be a buoyant ammonia jet (i.e., the ammonia vapor is less dense than air). However, for a given hole size and a given pressure, the rate of release of ammonia gas is very much less than that of liquid ammonia, so that it is unlikely that a vapor release would be the worst-case.

E.3.4 Equations for Log-log Graphs and Calculations

LOG-LOG EQUATIONS

The guidance on Figure E-2 is essentially in the form of a straight line on a log-log plot:

$$D = 0.0607(QR)^{0.4923} \quad (4)$$

for a rural site and

$$D = 0.0443(QR)^{0.4782} \quad (5)$$

for an urban site, where:

D = Distance to the endpoint (miles) and,

QR = Release rate (lb/min)

If you wish, you can use Equation 4 or 5 instead of Exhibit E-2 or Figure E-2.

The curves on Figure E-3 are approximately straight lines on a log-log plot:

$$D = 0.0222(QR)^{0.4780} \quad (6)$$

at a rural site, and

$$D = 0.0130(QR)^{0.4164} \quad (7)$$

at an urban site.

If you wish, you can use Equation 6 or 7 instead of Exhibit E-3 or Figure E-3.

ALTERNATIVE RELEASE SCENARIOS

There are many possible alternative scenarios. Some of those identified from a review of past incidents in refrigeration facilities include:

- Plant upsets leading to the lifting of relief valves
- Pipeline failures
- A blocked-in, liquid-full pipeline rupturing as it heats up
- Failures during ammonia delivery, such as a hose leak

The rule states that other scenarios, (discussed in Section 4.3 of the main document), should be considered. In addition, active and passive mitigation systems may be considered, provided that they can be shown to withstand the cause of the release. It is apparent that there is a great variety of alternative scenarios. However, EPA requires that only one such scenario be identified and modeled. Many scenarios are effectively equivalent to a small hole of diameter ¼ inch to ½ inch (e.g., a gasket rupture or a pump seal leak). Remember, however, that the alternative scenario must result in offsite consequences, unless you can show that no such scenario exists.

The rate of release QR for a liquid release through a hole may be calculated using Bernoulli's formula:

$$QR = c\sqrt{\rho}A(2Pg/\rho + 2gh)^{0.5}$$

where:

c = a constant (typical value 0.8)

ρ = the density of the liquid in the vessel (639 kg/m³ for ammonia)

A = the area of the hole (m²)

Pg = the gauge pressure in the vessel (Pa)

g = the acceleration due to gravity (9.82 m/s²)

h = the static head (m)

The static head is likely to be negligible when the tank pressure is high, as is likely for liquefied ammonia; therefore, the $2gh$ term in the equation can be ignored. The following equation drops the $2gh$ term and includes conversion factors:

$$QR = 132.2 \times 6.4516 \times 10^{-4} \times 0.8 \times 639 \times HA \times (2 \times (Pg/639) \times 6895)^{1/2}$$

where: QR = Release rate (pounds per minute)

HA = Hole area (square inches)

132.2 = Conversion factor for kilograms per second to pounds per minute

6.4516×10^{-4} = Conversion factor for square inches to square meters (HA)

0.8 = Discharge coefficient (0.8)

639 = Liquid density of ammonia (kg/m³)

Pg = Gauge pressure in tank (psi)

6,895 = Conversion factor for psi to Pascals (Pg)

Combining the conversion factors and incorporating the density of ammonia, leads to the equation presented in the text as Equation 3 for the release rate through a hole of ammonia liquefied under pressure:

$$QR = 203 \times HA \times (Pg)^{1/2}$$

Note that this is the formula for the release of a pure liquid and would apply to a breach in the wall of a vessel or to the rupture of a very short pipe. For long pipes, there is a pressure drop between the vessel and the hole that leads to flashing in the pipe and a reduced rate of release.

The scenario needs to be modeled in typical weather conditions. For many sites, Atmospheric Stability Category D with a moderate wind speed (e.g., 3 m/s) is close to average. The distance to the toxic endpoint can then be estimated from Figure E-3 or from Exhibit E-3, which is a tabulation of Figure E-3. These results could simply be quoted in the Risk Management Plan.

You also may identify your own alternative scenario(s). Consult your trade association (e.g., the International Institute of Ammonia Refrigeration) for guidance on other scenarios. Your Process Hazards Analysis is another potential source of pertinent information. However, remember that the regulation requires that releases large enough to have the potential to exceed the toxic endpoint offsite be considered.

E.3.5 Additional Guidance on Modeling

If the owner or operator decides to perform his/her own modeling, there are two major items that are not trivial. These are:

- a) Correct characterization of the source term (e.g., rate of release, temperature, density, momentum, aerosol content, etc.)
- b) Choice of a suitable dispersion model

It is not possible to cover in detail all of the issues that need to be addressed, although there are sources of useful advice. The quadrennial conferences on vapor cloud dispersion modeling that are organized by the Center for Chemical Process Safety (CCPS) are a good source of information on the latest developments in source term and dispersion modeling (CCPS, 1987, 1991, 1995). There are also CCPS Guidebooks, such as "Guidelines for Use of Vapor Cloud Dispersion Models - Second Edition".

EPA has also published additional guidance. There is one document that looks carefully at the definition of source terms (USEPA, 1993). There is another that describes EPA's own screening model for accidental releases of accidental chemicals TSCREEN (USEPA, 1992). EPA has also performed an evaluation of dense gas

dispersion models (USEPA, 1991). Another review of available models has been given by Hanna, et. al. (1991).

E.4 References and Additional Sources of Information

American National Standards Institute (1999), *American National Standard for Equipment, Design, and Installation of Ammonia Mechanical Refrigeration Systems*, ANSI/IIAR Standard 2.

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International Institute of Ammonia Refrigeration (1992). *Guidelines for Avoiding Component Failure in Industrial Refrigeration Systems Caused by Abnormal Pressure or Shock*, IIAR B-116.

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United States Environmental Protection Agency (USEPA, 2001). *Chemical Safety Alert: "Hazards of Ammonia Releases at Ammonia Refrigeration Facilities (Update),"* EPA 550-F-01-009. Available through EPA website at: www.epa.gov/emergencies.